

Appendix D – Hydropower and Forebay Analysis

**Whitney Lake Reallocation Study
Bosque and Hill Counties, Texas
DRAFT**

Integrated Feasibility Report and Environmental Assessment

July 2025



**US Army Corps
of Engineers®
FortWorth District**



US Army Corps
of Engineers®

Whitney Lake Water Storage Reallocation Study: Hydropower Analysis



DRAFT
May 2025

Contents

| | |
|--|----|
| Tables and Figures..... | 3 |
| Introduction | 4 |
| Background | 4 |
| Overall Approach and Study Alternatives | 5 |
| Hydropower Impacts..... | 7 |
| Impacts to Generation and Reserves | 8 |
| Energy and Reserves Value | 16 |
| Energy and Reserves Benefits and Impacts | 21 |
| Impacts to Dependable Capacity | 22 |
| SCE-TOM..... | 26 |
| Energy Linking Model (ELM) | 26 |
| Dependable Capacity Impacts..... | 27 |
| Hydropower Benefits Impacts Summary | 28 |
| Additional Sensitivity Analysis..... | 28 |
| Power Marketing Administration Impacts | 30 |
| Appendix A. Additional Model Documentation | 33 |
| Shuffled Complex Evolutionary – Turbine Optimization Algorithm | 33 |
| SCE-TOM Inputs | 34 |
| SCE-TOM Outputs | 35 |

Tables and Figures

| | |
|--|----|
| Figure 1 - Baseline Reservoir Allocations | 5 |
| Figure 2 - Average Annual Generation | 9 |
| Table 1 - Average Annual Generation by Driver | 9 |
| Table 2 - Average Annual Reserve (RRS) Provision | 10 |
| Figure 3 - Average Annual Reserve (RRS) Provision | 11 |
| Figure 4 - Average Annual Energy Generation by Month | 12 |
| Table 3 - Peak and Off-Peak Hours by Month | 13 |
| Figure 5 - Annual Average Generation by Peak/Off-Peak Period | 14 |
| Table 4 - Average Annual Energy Generation by Peak/Off-Peak Period..... | 15 |
| Figure 6 - Day-Ahead Hourly Energy Prices, ERCOT North Hub, 2017-2024 | 16 |
| Figure 7 - Day-Ahead Hourly Energy Prices, ERCOT North Hub, 2017-2024 (Zoomed view) | 17 |
| Figure 8 - EIA AEO 2023 Wholesale Energy Price Forecast for ERCOT | 18 |
| Table 5 - EIA AEO Reference Case vs. Side Case Comparison..... | 18 |
| Table 6 - Price Forecast Shaping Ratios by Month and Peak/Off-Peak Period | 19 |
| Table 7 - Levelized Price Forecast for ERCOT North Hub by Peak/Off-Peak Period..... | 20 |
| Figure 9 - Day-Ahead Hourly Responsive Reserve Prices, ERCOT North Hub, 2014-2024 | 21 |
| Table 8 - Levelized Responsive Reserve Price Forecast for ERCOT North Hub by Peak/Off-Peak Period | 21 |
| Table 9 - Average Annual Energy Benefits..... | 22 |
| Table 10 - Average Annual Reserves Benefits | 22 |
| Figure 10 - Dependable Capacity Analysis Process and Framework..... | 23 |
| Figure 11 - ERCOT System Peak Load, 2000-2023 | 24 |
| Figure 12 - ERCOT Monthly Load Forecast, 2024 - 2034..... | 25 |
| Figure 13 - Dependable Capacity | 27 |
| Table 11 - Dependable Capacity..... | 27 |
| Table 12 - Hydropower Benefits Summary | 28 |
| Figure 14 - Powerhill Mesh Sizing | 35 |

Introduction

This report presents the potential impacts to the hydropower of a potential water storage reallocation at Whitney Lake on the Brazos River in Texas. The analysis was performed by the USACE Hydropower Analysis Center (HAC) as a part of the Whitney Lake Reallocation Study executed by Ft. Worth District in 2023-2025. HAC evaluated several alternatives that reflect reallocation options to address increased municipal and industrial water supply in the region as represented by the study sponsor, the Brazos River Authority (BRA).

The primary results of this analysis are estimates of the impacts to the economic benefits associated with hydropower operations at the project and estimates of the revenue impacts to the Power Marketing Agency (PMA) responsible for the sale and delivery of the project's power, the Southwestern Power Administration (SWPA). HAC worked extensively with USACE staff at Ft. Worth District, Southwestern Division, and the Water Management and Reallocation Studies Planning Center of Expertise, as well as representatives from SWPA and the study sponsor, to ensure the rigor and accuracy of this analysis.

Background

Whitney Lake is located on the Brazos River (river mile 442.4) in Hill and Bosque Counties, Texas. The reservoir is approximately 38 river miles upstream from Waco, Texas, 19 miles southwest of Hillsboro and 81 miles by highway southwest from Dallas, Texas. The closest municipality is Whitney, Texas. The drainage area controlled by the dam is approximately 17,660 square miles of contributing drainage and 8,950 square miles non-contributing. The Brazos River Basin upstream of Whitney Dam extends northwest across a generally semi-arid region of Texas to its headwaters just across the Texas-New Mexico state line. The Brazos River flows to the Gulf of Mexico, with the mouth located near Freeport, Texas.

The powerhouse at Whitney Lake has two generating units that were upgraded in 2014 with a combined 42 MW nameplate capacity (21 MW each). SWPA markets the full output of the project at the contracted capacity amount of 36 MW; actual capacity provided can vary with project conditions. According to the project Water Control Manual (WCM), SWPA is currently allocated about 78% of the conservation pool and BRA is allocated the remaining 22%. Figure 1 illustrates the current reservoir allocations.

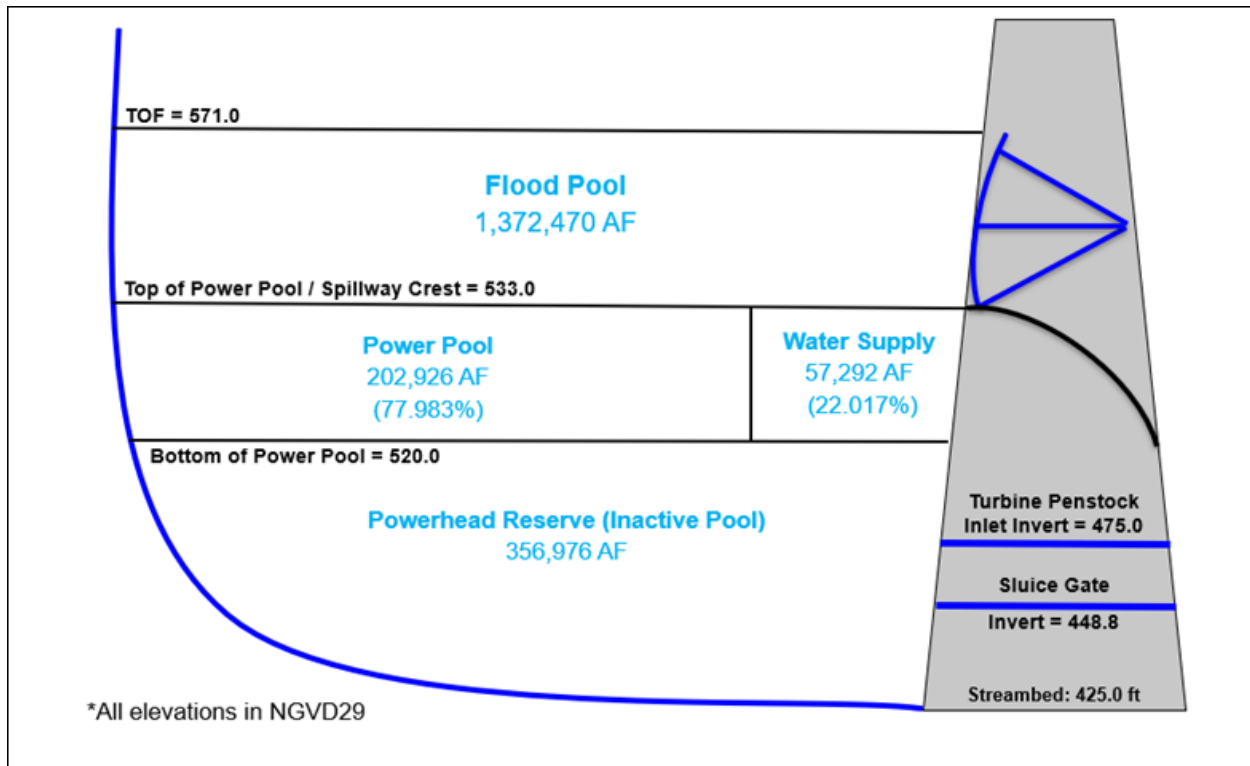


Figure 1 - Baseline Reservoir Allocations

Hydropower operations at Lake Whitney are noteworthy among USACE projects because, though it has been used primarily for peaking energy in the past, at this time SWPA’s customers primarily utilize the project’s capacity to provide spinning reserves capacity to the regional power market operated by The Electric Reliability Corporation of Texas (ERCOT). Generally speaking, most energy produced at the dam is the result of water supply and flood control related releases through the powerhouse, and releases for power production itself are relatively infrequent - occurring on fewer than 20 days per year.

In turn, ERCOT is noteworthy as a “energy-only” organized wholesale electricity market¹; in this region, generators are compensated through energy and ancillary services provision only, without a separate capacity market, unlike other deregulated US markets.

Overall Approach and Study Alternatives

Water flows through the Whitney Lake power plant for the period of record 1939-2022 were simulated by Ft. Worth district using RiverWare, a river and reservoir system modeling tool. HAC’s analysis is based in large part on RiverWare simulation results. The RiverWare model for Whitney Lake was based on multiple input parameters and assumptions, including those related to hydropower. One key assumption was the generation demand of SWPA’s customers. As mentioned above, these customers have utilized the hydropower capability of the project primarily to provide spinning reserve capacity, rather than

¹ The industry term “energy-only” is a misnomer intended to contrast specifically with regions with an organized capacity market. Firms in an “energy only market” explicitly trade both energy and ancillary services at market prices, with non-market mechanisms in place to ensure adequate long-term capacity procurement.

energy, to the regional market since 2014. Accordingly, relatively infrequent hydropower demand was assumed for this study – occurring on roughly twelve days per year on average - unlike in more typical storage reallocation study modeling. The assumed demand series was provided by SWPA, who coordinated with power customers to reflect current operations of the dam. In order to provide clarity and allow for a more rigorous analysis, the RiverWare model for this study was set up to calculate hydropower generation resulting from actual hydropower demand, generation resulting from water supply releases, and generation resulting from flood control-related releases separately. The uncommon operating regime similarly required special considerations related to the estimates of dependable capacity and benefits associated with spinning reserves, which are discussed in their corresponding sections below.

The impacts of the following alternative scenarios are analyzed herein. These alternatives were selected from a larger list considered in the development of this study; full descriptions of each and the screening process can be found in the main report. Each alternative essentially assumes a different reallocation away from hydropower and towards water supply, with or without additional actions related to reservoir management.

- **Alternative 1** (baseline, future without project, no-action alternative): Brazos River Authority (BRA) is authorized 22.017% of the conservation pool and Southwestern Power Administration (SWPA) is authorized 77.983% of the conservation pool, as specified in the Water Control Manual (WCM). The conservation pool is the amount of water stored between elevations 520.0' and 533.0'.
- **Alternative 2**: BRA is allocated 67% of the conservation pool and SWPA is allocated 33% of the conservation pool. The conservation pool is the amount of water stored between elevations 520.0' and 533.0'.
- **Alternative 2a**: BRA is allocated 50% of the conservation pool and SWPA is allocated 50% of the conservation pool. The conservation pool is the amount of water stored between elevations 520.0' ft and 533.0' ft.
- **Alternative 2c**: Conservation pool (upper) – Reallocation to water supply that leaves the least SWPA storage where peaking demand series is unaffected.
- **Alternative 3**: The top of conservation pool is increased from 533.0' to 536.0'. The additional storage is credited to BRA. BRA is allocated 39.2% of the conservation pool and SWPA is allocated 60.8% of the conservation pool. The conservation pool is the amount of water stored between elevations 520.0' and 536.0'.
- **Alternative 4**: The bottom of conservation pool is decreased from 520.0' to 518.4'. The additional storage is credited to BRA. BRA is allocated 28.68% of the conservation pool and SWPA is allocated 71.32% of the conservation pool. The conservation pool is the amount of water stored between elevations 518.4' and 533.0'.
- **Alternative 5**: The current conservation pool (520.0 – 533.0) is equally divided between water supply and hydropower. The top of conservation pool is increased from 533.0' to 534.5. The additional storage is credited to BRA. BRA is allocated 56.1% of the conservation pool and SWPA is allocated 43.9% of the conservation pool. The conservation pool is the amount of water stored between elevations 520' and 534.5'.
- **Tentatively Selected Plan (TSP)**: This alternative is a combination of Alternatives 2a and 4. The upper conservation pool (520.0 – 533.0) is equally divided between water supply and

hydropower. Then, the bottom of the conservation pool is decreased from 520.0ft to 512.0 ft. The additional storage is credited to the Brazos River Authority. The conservation pool is the amount of water stored between elevations 512.0 ft and 533 ft.

The following general assumptions underlie HAC’s evaluation. Other specific assumptions and inputs enter the analysis and are described in the relevant sections below.

- The hydrologic period of record for RiverWare modeling was 1939 – 2022
- Hydropower benefits were calculated over a 50-year future period starting in 2025
- The analysis employs the FY 2025 federal discount rate of 3% throughout
- All dollar figures are stated in constant FY 2025 dollars

Hydropower Impacts

HAC’s analysis centers on the National Economic Development (NED) benefits arising from hydropower operations at Lake Whitney. These benefits stem from multiple related but distinct power products and services marketed from hydropower plants. The USACE guidance related to the computation of hydropower benefits is outlined in EM 1101-2-1701 *Hydropower*, and ER 1105-2-100, *Planning Guidance Notebook*. The guidelines require that the reallocation cost charged to the water supply customer be the highest of hydropower benefits foregone (lost to reallocation)², PMA revenues foregone, or the updated cost of water storage.

Electricity systems are unique among economic markets in that supply must meet demand at all time. Any imbalance, even if momentary, can cause equipment failures, damage, and grid blackouts. As a result, the output exchanged in wholesale electricity markets takes the form of several different goods and services, rather than a single commodity, that together ensure continuous system operation and reliability. Broadly speaking, these products are typically bought and sold as “energy”, “capacity”, and a group of reliability tools collectively called “ancillary services” that includes reserve capacity.

Energy generation refers to the electrical energy supplied by a combination of current and electrical potential, delivered by wires from generator to consumer. Typically measured in kilowatt-hours (kWh) or megawatt-hours (MWh), energy can be thought of as roughly analogous to the commodity delivered in a more conventional market.

Capacity in this context refers to the ability of a generating resource or system to deliver energy, usually measured in megawatts (MW). Market participants and system operators typically focus on “firm” or “dependable” capacity, which is the maximum ability of a generator to contribute to system needs under adverse demand (load) and supply conditions. In some regions, capacity is bought and sold separately from energy; in others, capacity is effectively bundled with energy and ancillary services via spot market prices or embedded with energy in long-term bilateral contracts.

Ancillary Services are grid reliability tools that ensure continuous operation at often very small time scales (i.e., milliseconds to minutes). The ancillary service relevant to this study is called “spinning

² Guidelines also indicate that the replacement cost of power be considered in this determination. HAC’s valuation of power benefits is based on market value, which represents the replacement cost of power. Power benefits foregone and the replacement cost of power are therefore identical.

reserve” capacity, which system operators require over and above the capacity needed to meet expected loads to cover unforeseen disruptions such as power plant outages or transmission failures.

Energy systems consist of highly regulated and interlinked markets overseen by federal, regional, and local government entities. Market participants such as utilities that are responsible for serving electric customers are required by law to obtain each of these products in sufficient amounts to ensure safe and reliable service. Specifically, the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), and the State of Texas all require the production or procurement of energy, firm capacity, and ancillary services by system operators.

Because ERCOT is an “energy-only” market region, the monetary value of capacity – in other words, the fixed costs associated with constructing, operating, and maintaining a power plant – is in principle embedded within wholesale energy and ancillary services prices, rather than in an additional and separable value. Dependable capacity impacts are consequently presented in this study in terms of megawatts but not in monetary terms distinct from energy and reserves benefits.

Impacts to Generation and Reserves

Reallocation of storage in the Lake Whitney reservoir impacts the provision of both energy and spinning reserves – called “Responsive Reserve Service” (RRS) in the ERCOT market. The estimated average annual impacts to energy generation and RRS of the proposed alternatives are based on RiverWare simulations provided by Ft. Worth district. RiverWare produces daily simulated energy generation and other information for the period of record. To derive estimated reserves provision using RiverWare’s energy-related output, HAC coordinated with dam operations staff and SWPA to establish an assumption that reflects actual power customer behavior. The assumption is that RRS will be provided to the day-ahead market for all hours of the day when water releases for power generation, flood control, or water supply do not occur, except for an additional two-hour period following dam releases during which no releases occur.

Figure 2 and Table 1 below summarizes the annual average energy produced at the project under baseline and alternative scenarios. As noted above, energy generation driven by power customer demand is limited at Lake Whitney in favor of spinning reserves (RRS). Estimates are accordingly presented by driver of the generation – either at power customers’ request or via water supply/flood release.

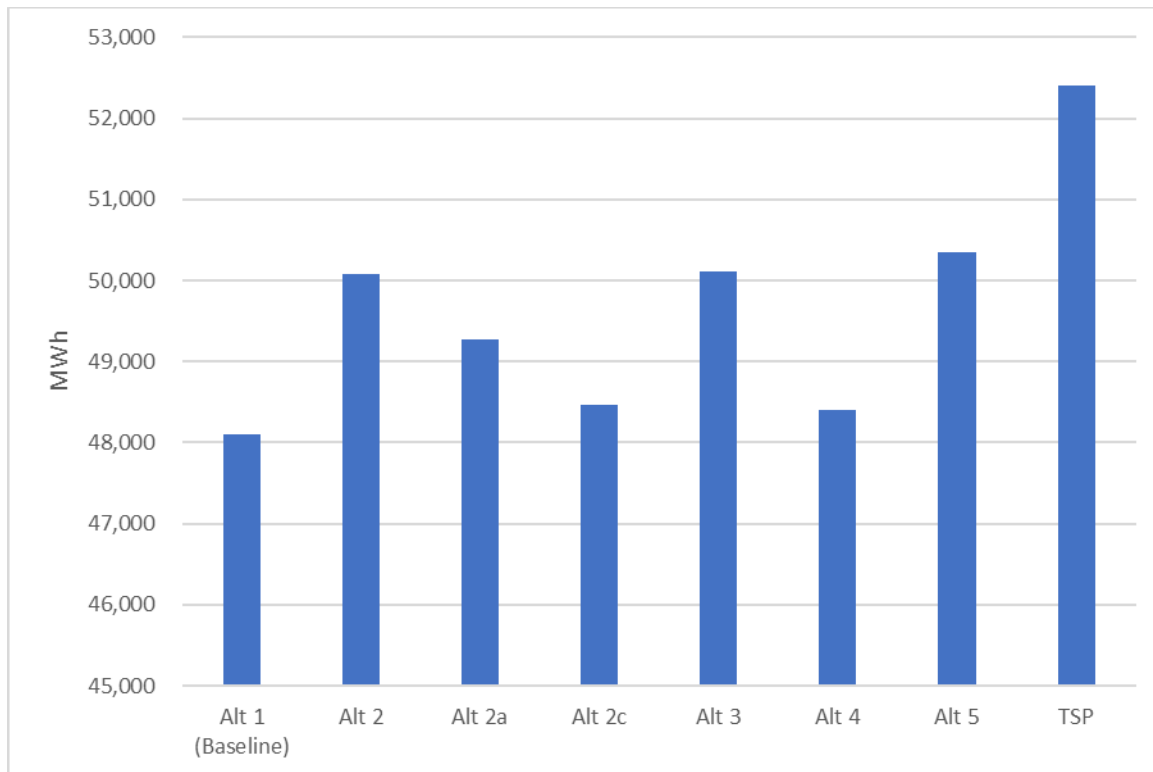


Figure 2 - Average Annual Generation

Table 1 - Average Annual Generation by Driver

| | Non-Customer-Driven Generation (MWh) | Hydropower Customer-Driven Generation (MWh) | Total Generation (MWh) | Change from Baseline | % Change from Baseline |
|---------------|--------------------------------------|---|------------------------|----------------------|------------------------|
| Alt 1 | 46,185 | 1,914 | 48,098 | N/A | N/A |
| Alt 2 | 48,376 | 1,705 | 50,082 | 1,984 | 4.1% |
| Alt 2a | 47,400 | 1,878 | 49,279 | 1,180 | 2.5% |
| Alt 2c | 46,545 | 1,921 | 48,465 | 367 | 0.8% |
| Alt 3 | 48,171 | 1,934 | 50,106 | 2,007 | 4.2% |
| Alt 4 | 46,485 | 1,919 | 48,404 | 305 | 0.6% |
| Alt 5 | 48,472 | 1,874 | 50,347 | 2,249 | 4.7% |
| TSP | 50,538 | 1,871 | 52,409 | 4,311 | 9.0% |

As expected, generation impacts are relatively small to modest, and generally positive – reallocation away from hydropower storage actually *increases* total hydropower generation across most alternatives – due to the unique hydropower operating regime at Whitney Lake. The TSP is the most impactful, with an average annual increase in energy output of 9% over the baseline.

It is important to note that because hydropower storage is utilized primarily to provide RRS rather than energy, an increase in generation does not necessarily reflect the preference of SWPA or its customers. Table 2 and Figure 3 below summarize the impact to reserves provision for each of the alternatives. These impacts naturally tend to occur in the opposite direction as those to energy generation, given that reserves and energy are effectively substitute outputs in this context. Notable exceptions are Alternatives 3 and 5, which increase both generation (via increased water supply releases) and reserves (via increased operating head, and thus power capability). The TSP has the most negative impact to reserves provision, with an average annual change of -3.5%.

Table 2 - Average Annual Reserve (RRS) Provision

| | Average Annual RRS MWh | Change from Baseline | % Change from Baseline |
|-------------------------|-------------------------------|-----------------------------|-------------------------------|
| Alt 1 (Baseline) | 315,866 | 0 | 0.0% |
| Alt 2 | 310,732 | -5,134 | -1.6% |
| Alt 2a | 312,714 | -3,152 | -1.0% |
| Alt 2c | 314,778 | -1,088 | -0.3% |
| Alt 3 | 328,439 | 12,573 | 4.0% |
| Alt 4 | 314,954 | -911 | -0.3% |
| Alt 5 | 319,260 | 3,394 | 1.1% |
| TSP | 304,893 | -10,972 | -3.5% |

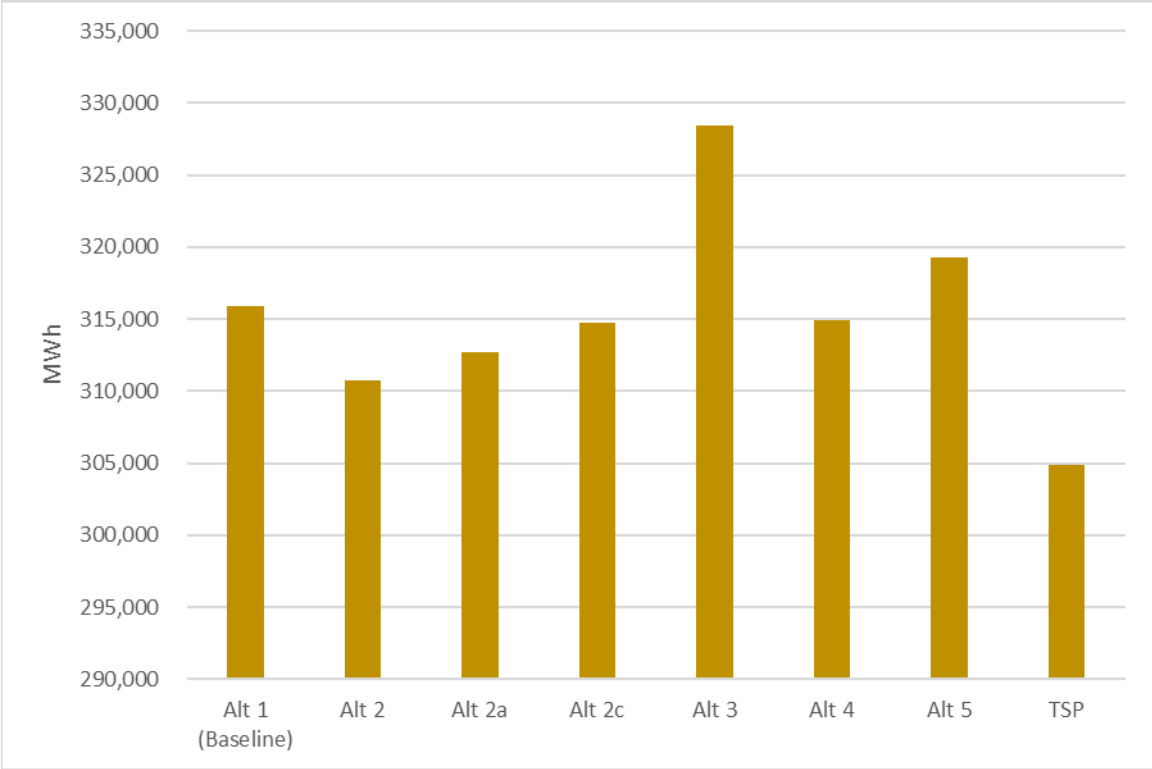


Figure 3 - Average Annual Reserve (RRS) Provision

Lake Whitney hydropower operations, regional energy prices, and the bulk electricity system as a whole vary according to hydrology, weather, market conditions, and other factors that change materially throughout a given day, month, and year. It is thus necessary to estimate impacts on an appropriately detailed time scale for the purpose of calculating economic benefits. For illustration, Figure 4 shows the monthly distribution of energy generation across study alternatives.

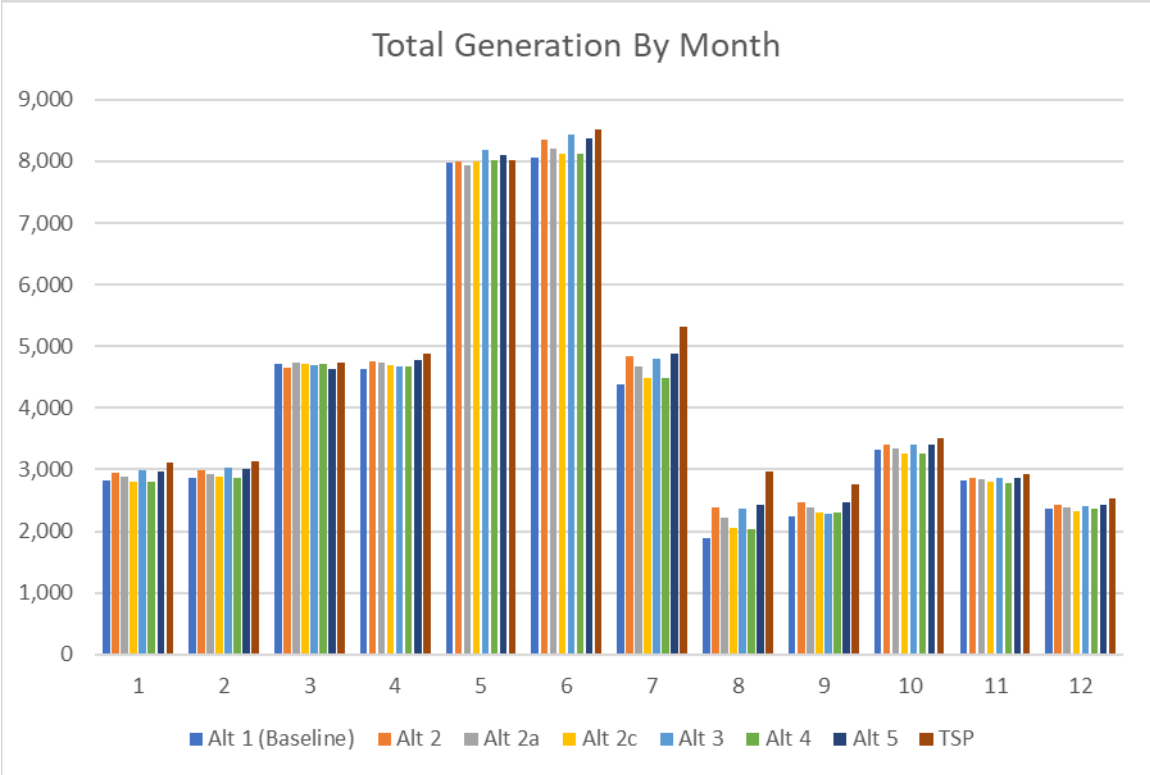


Figure 4 - Average Annual Energy Generation by Month

Figure 4 shows that generation tends to correlate with the rainy spring and winter seasons, driven by flood control releases through the powerhouse, and is lowest during the dry late summer.

Generation also varies throughout the hours of the day, and this variation does reflect hourly patterns in power demand, prices, and other market factors. For this study, daily simulated generation from RiverWare was allocated by HAC (outside the model) to “peak” and “off-peak” periods of the day for valuation purposes. These blocks of hours are defined primarily by the high electricity demand periods in the mid-morning (roughly 6:00am – 10:00am) and afternoon and early evening (3:00pm – 8:00pm). SWPA provided the following monthly schedule of peak and off-peak hours (Table 3), wherein a correlation between daily peak period duration and high or low temperatures is evident.

Table 3 - Peak and Off-Peak Hours by Month

| Month | Number of daily peak hours | Number of daily off-peak hours |
|--------------|-----------------------------------|---------------------------------------|
| 1 | 9 | 15 |
| 2 | 3 | 21 |
| 3 | 6 | 18 |
| 4 | 6 | 18 |
| 5 | 10 | 14 |
| 6 | 8 | 16 |
| 7 | 10 | 14 |
| 8 | 10 | 14 |
| 9 | 10 | 14 |
| 10 | 9 | 15 |
| 11 | 3 | 21 |
| 12 | 5 | 19 |

The allocation from daily to peak/off-peak blocks was based on the assumption that actual releases through the powerhouse would be strategically timed to occur during peak hours. Daily totals were first allocated to peak hours up to the maximum potential, then the remaining generation for the day was allocated to off-peak hours. This assumption was verified with USACE operations and SWPA staff.

Figure 5 summarizes annual average generation by peak and off-peak periods. Table 4 presents a full monthly summary of this data.

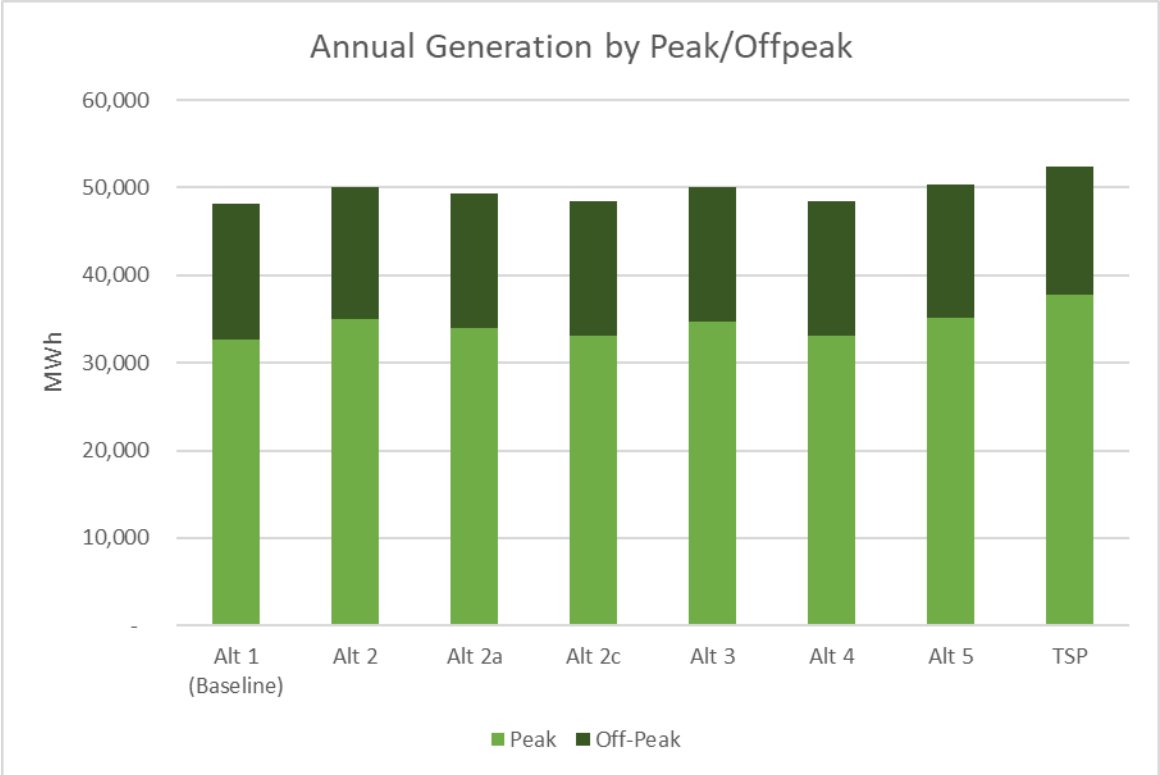


Figure 5 - Annual Average Generation by Peak/Off-Peak Period

Table 4 - Average Annual Energy Generation by Peak/Off-Peak Period

| Month | | Alt 1 (Baseline) | Alt 2 | Alt 2a | Alt 2c | Alt 3 | Alt 4 | Alt 5 | TSP |
|--------|----------|------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | Peak | 2,317 | 2,459 | 2,379 | 2,297 | 2,454 | 2,297 | 2,450 | 2,626 |
| | Off-Peak | 500 | 496 | 497 | 508 | 527 | 503 | 523 | 487 |
| | Total | 2,817 | 2,955 | 2,876 | 2,805 | 2,982 | 2,800 | 2,973 | 3,112 |
| 2 | Peak | 1,193 | 1,347 | 1,269 | 1,207 | 1,325 | 1,199 | 1,341 | 1,517 |
| | Off-Peak | 1,679 | 1,647 | 1,660 | 1,672 | 1,701 | 1,673 | 1,676 | 1,613 |
| | Total | 2,872 | 2,994 | 2,929 | 2,878 | 3,027 | 2,872 | 3,017 | 3,129 |
| 3 | Peak | 2,774 | 2,757 | 2,851 | 2,803 | 2,862 | 2,799 | 2,750 | 2,983 |
| | Off-Peak | 1,936 | 1,891 | 1,888 | 1,917 | 1,832 | 1,924 | 1,878 | 1,760 |
| | Total | 4,710 | 4,649 | 4,739 | 4,721 | 4,695 | 4,723 | 4,628 | 4,743 |
| 4 | Peak | 2,840 | 3,001 | 2,949 | 2,892 | 2,895 | 2,880 | 3,011 | 3,165 |
| | Off-Peak | 1,797 | 1,757 | 1,787 | 1,794 | 1,771 | 1,786 | 1,767 | 1,722 |
| | Total | 4,637 | 4,758 | 4,736 | 4,686 | 4,666 | 4,665 | 4,778 | 4,887 |
| 5 | Peak | 5,992 | 6,056 | 5,942 | 6,022 | 6,090 | 6,019 | 6,069 | 6,088 |
| | Off-Peak | 1,982 | 1,951 | 1,995 | 1,979 | 2,088 | 1,997 | 2,031 | 1,928 |
| | Total | 7,974 | 8,007 | 7,937 | 8,001 | 8,178 | 8,016 | 8,099 | 8,016 |
| 6 | Peak | 5,264 | 5,570 | 5,454 | 5,338 | 5,646 | 5,331 | 5,611 | 5,796 |
| | Off-Peak | 2,791 | 2,793 | 2,762 | 2,789 | 2,792 | 2,784 | 2,772 | 2,719 |
| | Total | 8,055 | 8,362 | 8,216 | 8,127 | 8,439 | 8,115 | 8,383 | 8,515 |
| 7 | Peak | 3,785 | 4,241 | 4,076 | 3,907 | 4,205 | 3,873 | 4,289 | 4,716 |
| | Off-Peak | 596 | 589 | 596 | 583 | 600 | 605 | 583 | 595 |
| | Total | 4,381 | 4,830 | 4,672 | 4,489 | 4,804 | 4,477 | 4,872 | 5,311 |
| 8 | Peak | 1,689 | 2,185 | 2,015 | 1,859 | 2,150 | 1,829 | 2,233 | 2,787 |
| | Off-Peak | 198 | 197 | 204 | 196 | 208 | 197 | 201 | 180 |
| | Total | 1,886 | 2,382 | 2,219 | 2,056 | 2,358 | 2,026 | 2,434 | 2,967 |
| 9 | Peak | 2,001 | 2,256 | 2,168 | 2,085 | 2,047 | 2,074 | 2,250 | 2,519 |
| | Off-Peak | 242 | 216 | 212 | 228 | 229 | 230 | 220 | 235 |
| | Total | 2,243 | 2,472 | 2,380 | 2,313 | 2,276 | 2,304 | 2,470 | 2,754 |
| 10 | Peak | 2,435 | 2,541 | 2,484 | 2,392 | 2,520 | 2,383 | 2,536 | 2,691 |
| | Off-Peak | 893 | 854 | 860 | 877 | 876 | 877 | 871 | 826 |
| | Total | 3,328 | 3,395 | 3,344 | 3,268 | 3,396 | 3,260 | 3,407 | 3,516 |
| 11 | Peak | 976 | 1,090 | 1,026 | 971 | 1,064 | 972 | 1,079 | 1,223 |
| | Off-Peak | 1,849 | 1,770 | 1,822 | 1,821 | 1,808 | 1,816 | 1,782 | 1,696 |
| | Total | 2,825 | 2,860 | 2,848 | 2,792 | 2,872 | 2,788 | 2,860 | 2,919 |
| 12 | Peak | 1,399 | 1,486 | 1,421 | 1,388 | 1,473 | 1,393 | 1,483 | 1,624 |
| | Off-Peak | 971 | 932 | 961 | 942 | 942 | 964 | 941 | 914 |
| | Total | 2,369 | 2,418 | 2,382 | 2,329 | 2,414 | 2,356 | 2,424 | 2,538 |
| Annual | Peak | 32,664 | 34,989 | 34,034 | 33,160 | 34,731 | 33,049 | 35,102 | 37,735 |
| | Off-Peak | 15,434 | 15,092 | 15,245 | 15,305 | 15,375 | 15,355 | 15,245 | 14,673 |
| | Total | 48,098 | 50,082 | 49,279 | 48,465 | 50,106 | 48,404 | 50,347 | 52,409 |

Energy and Reserves Value

The estimated economic benefits associated with the energy and reserves summarized above are based on a detailed energy price forecast for the regional electricity market. This forecast takes annual, monthly, daily, and hourly variation of energy prices, as well as geography-specific factors that impact market supply and demand, into account. Forecasts of energy and RRS prices were developed from historical data available from ERCOT, and regional wholesale price forecasts published by the US Energy Information Administration (US EIA).

Historical hourly day-ahead³ Locational Marginal Price (LMP) data for the most recent 6 years (2018-2023) was obtained directly from the ERCOT website⁴ (Figure 6). Locational marginal pricing is a mechanism used in wholesale electricity markets to determine the price of electricity at specific geographic locations, taking transmission constraints and generating resource dispersion and availability into account. ERCOT's somewhat uncommon market design tends to allow extreme price spikes during periods of tight supply in order to incentivize capacity investment without a formal forward capacity market. These relatively infrequent spikes make Figure 6 difficult to interpret due to scale; Figure 7 shows a closer view of hourly prices by limiting the axis to \$300/MWh.

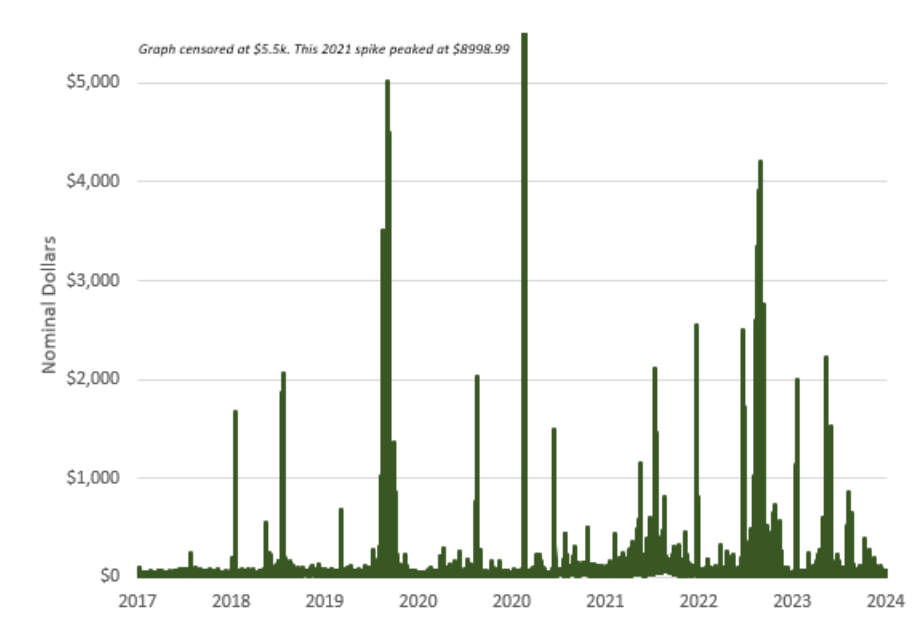


Figure 6 - Day-Ahead Hourly Energy Prices, ERCOT North Hub, 2017-2024

³ Electricity generators and buyers (e.g., distribution companies) trade energy in ERCOT's day-ahead and real-time markets in ERCOT, as well as through other arrangements outside the organized market. ERCOT load-responsible entities currently cover a majority (59%) of their demand in the ERCOT day-ahead market, locking-in prices ahead of possible price risk in the real-time market, and it is HAC's understanding that the hydropower customers utilizing Whitney Lake's capability primarily utilize the day-ahead market for their transactions.

⁴ <https://www.ercot.com/mktinfo/prices>

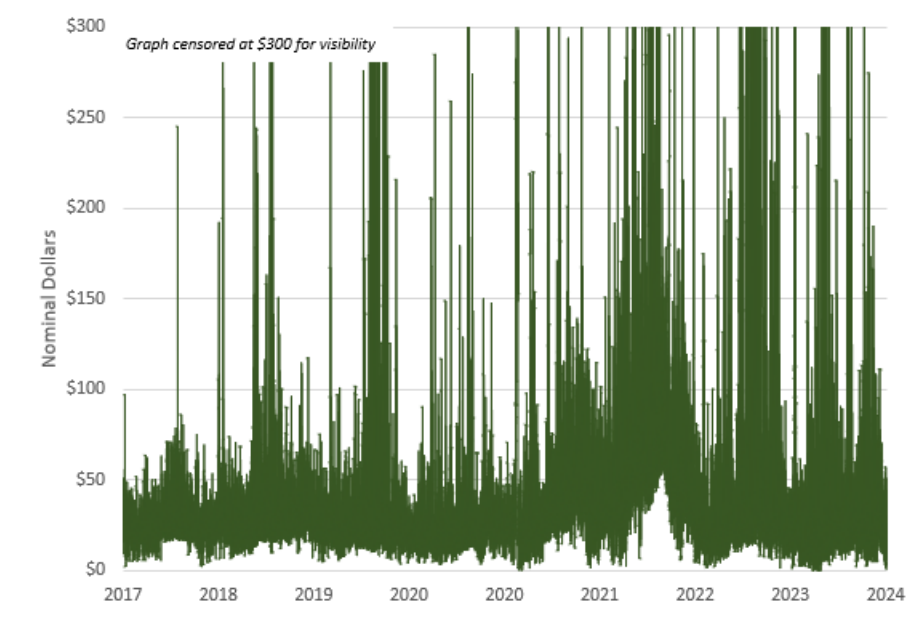


Figure 7 - Day-Ahead Hourly Energy Prices, ERCOT North Hub, 2017-2024 (Zoomed view)

The EIA publishes an Annual Energy Outlook (AEO) that includes thirty years of annual average forecasted wholesale energy prices for market regions and subregions of the US. The EIA's 2023 AEO forecast formed the basis of the hourly and location-specific LMP forecast used to value the replacement cost of Lake Whitney's hydropower output. Because the AEO forecast only spans 26 years through 2050, prices were assumed to remain constant in real terms for the remaining 24 years of this study's 50-year horizon. The AEO includes several scenarios – a Reference Case that serves as a baseline forecast (and which is used for the valuations in this study), and several alternative scenarios that take into account the uncertainty associated with different possible market conditions. These side cases are defined by assumptions regarding macroeconomic conditions, global oil and gas prices and supply, and renewable energy resource costs⁵. Figure 8 illustrates the AEO forecasts, and Table 5 summarizes the variability across cases, which reflect how sensitive the benefits estimates presented next would be to uncertainty to this variable. Overall, prices across the 50-year forecast period range from roughly -6% to +12% about the Reference Case.

⁵ Full descriptions of forecast cases are available on the EIA website, www.eia.gov/outlooks/aeo/assumptions/case_descriptions.php

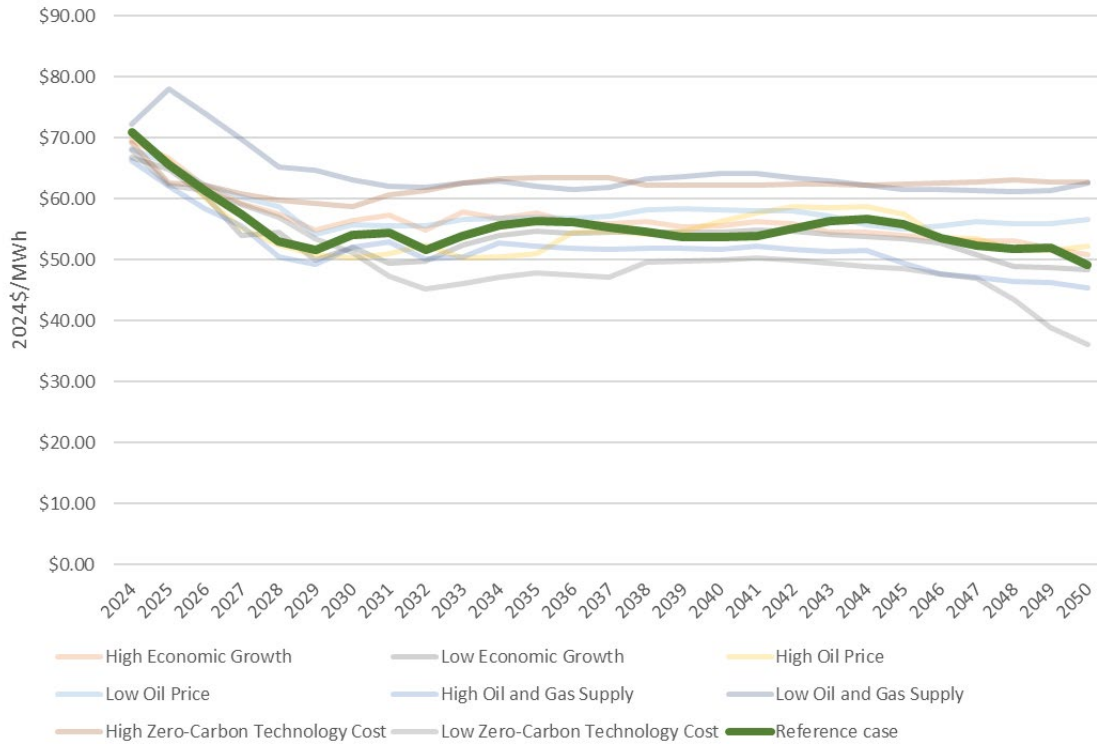


Figure 8 - EIA AEO 2023 Wholesale Energy Price Forecast for ERCOT

Table 5 - EIA AEO Reference Case vs. Side Case Comparison

| | Levelized Price Through 2050 | Difference from Reference Case |
|----------------------------------|-------------------------------------|---------------------------------------|
| Reference case | \$54.06 | n/a |
| High Economic Growth | \$54.96 | 1.7% |
| Low Economic Growth | \$52.95 | -2.1% |
| High Oil Price | \$53.66 | -0.7% |
| Low Oil Price | \$55.59 | 2.8% |
| High Oil and Gas Supply | \$51.64 | -4.5% |
| Low Oil and Gas Supply | \$60.40 | 11.7% |
| High Zero-Carbon Technology Cost | \$58.51 | 8.2% |
| Low Zero-Carbon Technology Cost | \$50.63 | -6.3% |

The EIA’s annual price forecast is used to project LMP energy prices through a relatively simple process:

- First, the historical relationship between the *annual* and *region-wide* values reported by the EIA and the *hourly* and *location-specific* LMP values is established for each generation block (i.e., peak and off-peak) of the day.
- These estimated relationships are then applied to future forecasted values from the EIA to produce generation block and location specific forecasted LMP values.

The historical relationships between the EIA values and the LMP values are estimated by calculating the ratio of LMP value (for the hour of the year) to the annual EIA-forecasted value for the preceding five-year (2018-2023, excluding 2021) period, then averaging these hourly ratios within each of the peak/off-peak generation blocks described above for each month of the year. HAC refers to these average ratios as “shaping ratios”. To match the hourly LMP data with the generation blocks, the price data was sorted from high to low within each day, implying that the highest LMP values are associated with the highest value block. Table 6 summarizes the resulting shaping ratios for each generation block and month of the year. These shaping ratios are interpretable as percentages – for example, the LMP is expected to be about 60% of the regional annual average price during January peak periods. And 36% of the regional average during off-peak periods.

Table 6 - Price Forecast Shaping Ratios by Month and Peak/Off-Peak Period

| Month | Peak | Off-Peak |
|--------------|-------------|-----------------|
| 1 | 0.60 | 0.36 |
| 2 | 0.67 | 0.35 |
| 3 | 0.70 | 0.36 |
| 4 | 0.70 | 0.38 |
| 5 | 0.84 | 0.39 |
| 6 | 0.87 | 0.43 |
| 7 | 1.58 | 0.41 |
| 8 | 1.90 | 0.45 |
| 9 | 1.15 | 0.40 |
| 10 | 0.70 | 0.37 |
| 11 | 0.81 | 0.43 |
| 12 | 0.79 | 0.42 |

The resulting Reference Case levelized LMP forecast is collected in Table 7.

Table 7 - Levelized Price Forecast for ERCOT North Hub by Peak/Off-Peak Period

| Month | Peak | Off-Peak |
|--------------|-------------|-----------------|
| 1 | \$33.50 | \$19.85 |
| 2 | \$37.19 | \$19.56 |
| 3 | \$38.69 | \$19.90 |
| 4 | \$38.96 | \$20.89 |
| 5 | \$46.60 | \$21.83 |
| 6 | \$48.62 | \$23.68 |
| 7 | \$87.92 | \$22.89 |
| 8 | \$105.81 | \$25.01 |
| 9 | \$63.81 | \$22.25 |
| 10 | \$38.97 | \$20.52 |
| 11 | \$45.16 | \$23.70 |
| 12 | \$44.15 | \$23.42 |

Reserves prices are a function of energy prices. The owners of power plants across an electricity system choose their operating regime in order to maximize profit and/or minimize the costs of meeting their own system’s needs, subject to market economics and their plants’ operating constraints. In essence, generators choose which combination of energy, capacity, and other ancillary services to produce. In an “energy-only” market like ERCOT, producers choose between megawatts of generation and megawatts of an ancillary service like RRS. Because these two options are mutually exclusive (a plant cannot simultaneously produce energy and RRS), the market RRS price reflects the opportunity cost of *not* generating and selling energy at its market price. Figure 9 summarizes the recent history of ERCOT RRS prices. The figure shows that these are generally materially lower than energy prices, but like the energy prices in Figure 6 above, occasional extreme spikes characterize the series.

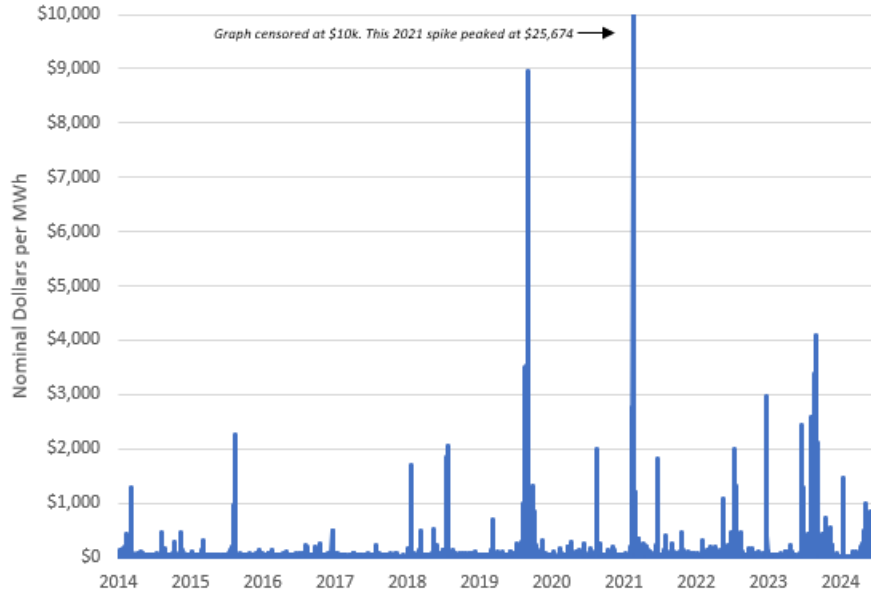


Figure 9 - Day-Ahead Hourly Responsive Reserve Prices, ERCOT North Hub, 2014-2024

Given that RRS prices are a function of energy prices, the same general approach described above to produce an energy price forecast was used to produce a forecast of RRS prices. Table 8 summarizes the resulting RRS price forecast.

Table 8 - Levelized Responsive Reserve Price Forecast for ERCOT North Hub by Peak/Off-Peak Period

| Month | Peak | Off-Peak |
|-------|---------|----------|
| 1 | \$19.90 | \$6.33 |
| 2 | \$24.34 | \$7.69 |
| 3 | \$25.64 | \$9.05 |
| 4 | \$24.71 | \$9.52 |
| 5 | \$26.02 | \$5.44 |
| 6 | \$24.96 | \$3.69 |
| 7 | \$59.13 | \$2.59 |
| 8 | \$75.83 | \$2.48 |
| 9 | \$47.79 | \$2.96 |
| 10 | \$23.86 | \$6.59 |
| 11 | \$29.36 | \$10.21 |
| 12 | \$30.31 | \$9.98 |

Energy and Reserves Benefits and Impacts

Combining the block-specific price forecasts presented immediately above with the block-specific energy and RRS simulation results presented earlier produces estimates of the value of hydropower production in each of this study’s alternatives. Table 9 summarizes these average annual impacts to energy benefits,

and Table 10 summarizes the annual impacts to reserves benefits that the alternatives would have during a 50-year period.

Table 9 - Average Annual Energy Benefits

| | Average Annual 2025\$ | Change from Baseline | % Change from Baseline |
|-------------------------|------------------------------|-----------------------------|-------------------------------|
| Alt 1 (Baseline) | \$2,051,991 | \$0 | 0.0% |
| Alt 2 | \$2,200,544 | \$148,553 | 7.2% |
| Alt 2a | \$2,142,905 | \$90,914 | 4.4% |
| Alt 2c | \$2,088,834 | \$36,843 | 1.8% |
| Alt 3 | \$2,188,152 | \$136,160 | 6.6% |
| Alt 4 | \$2,081,627 | \$29,635 | 1.4% |
| Alt 5 | \$2,214,025 | \$162,034 | 7.9% |
| TSP | \$2,371,258 | \$319,267 | 15.6% |

Table 10 - Average Annual Reserves Benefits

| | Average Annual 2025\$ | Change from Baseline | % Change from Baseline |
|-------------------------|------------------------------|-----------------------------|-------------------------------|
| Alt 1 (Baseline) | \$4,686,168 | \$0 | 0.0% |
| Alt 2 | \$4,532,770 | -\$153,398 | -3.3% |
| Alt 2a | \$4,590,497 | -\$95,670 | -2.0% |
| Alt 2c | \$4,647,672 | -\$38,496 | -0.8% |
| Alt 3 | \$4,834,511 | \$148,344 | 3.2% |
| Alt 4 | \$4,654,968 | -\$31,199 | -0.7% |
| Alt 5 | \$4,670,040 | -\$16,128 | -0.3% |
| TSP | \$4,358,261 | -\$327,907 | -7.0% |

Two patterns are worth noting in Tables 9 and 10. First, due to hourly and seasonal variation in energy and reserves prices, impacts in monetary terms are generally larger than impacts measured in physical units (i.e., megawatts and megawatt-hours). Second, due to relative prices of energy and reserves, many of the positive impacts to energy benefits in Table 9 are coincidentally similar in magnitude to the corresponding negative impacts to reserves in Table 10. The combined net impact for a given alternative, presented in Table 12 below, are thus generally small.

Impacts to Dependable Capacity

The dependable capacity of a power plant is a measure of the amount of power that it can reliably contribute towards meeting system peak power demand. For thermal generating resource such as a natural gas or coal-fired plant, fuel is often considered to be unlimited, and the plant's dependable capacity (often called "firm" capacity) is a relatively simple function of its forced outage rate. For an energy-limited resource like a hydropower plant, dependable capacity is a more complicated function of

the project’s installed generating capacity, the availability of water (for fuel), and the timing of regional system peak load.

If a hydropower plant always maintained the same operating head and there was always an adequate supply of stream flow to make its full capacity available to carry system load, then a hydropower plant would be much like a thermal resource in terms of dependable capacity. At storage hydropower projects, normal reservoir drawdown results in a reduction of dependable capacity due to loss of operating head and a loss of available energy. Dependable capacity accounts for these factors by giving a measure of the amount of capacity that can be provided with an acceptable degree of certainty – that is, the amount that a plant can provide during adverse demand (peak load) and adverse supply (constrained hydrology) conditions.

EM 1110-2-1701 outlines several largely overlapping methods for calculating dependable capacity, noting that the method depends on the type of project and type of power system in this the project operates. Historically, HAC has utilized elements of the “Specified Availability”, “Average Availability”, “Critical Month”, and the “Firm Plant Factor” methods⁶ in calculating dependable capacity using modeling and analytical tools developed since the EM was published. The method used for this study is intended to accurately capture the plant’s actual firm capability in the context of a somewhat uncommon reserves-focused operating regime. Figure 10 below presents an overview of the process used. In short, the daily output of RiverWare model simulation was used as an input to HAC’s hourly energy simulation modeling suite to generate hourly-level estimates of plant capacity under critical demand and supply conditions. A detailed description of the process follows.

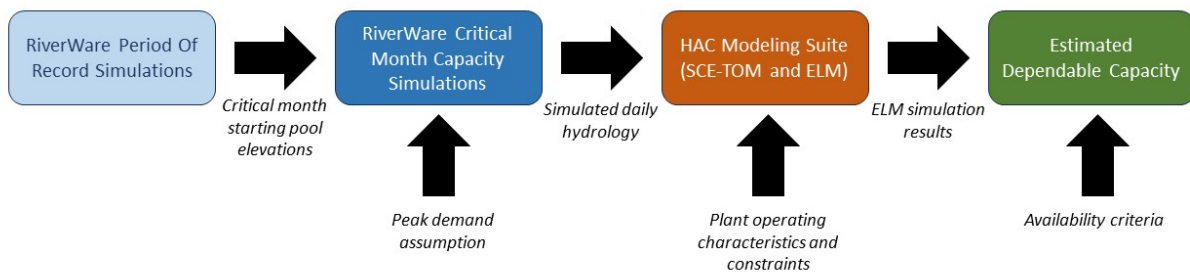


Figure 10 - Dependable Capacity Analysis Process and Framework

The first step in determining the plant’s dependable capacity was to identify the critical hydrologic and load months during which the plant’s capabilities would be most limited and demand on the regional energy system would be highest. Though ERCOT has both summer and winter peak loads driven primarily by weather conditions, its highest annual peak occurs in the summer, most commonly in August (Figure 11). Further, ERCOT’s mid-term load forecast shows the system annual peak (MW) and highest energy consumption (MWh) continuing to occur during the month of August (Figure 12).

⁶ EM 1110-2-1701, Section 6-7. *Dependable Capacity*

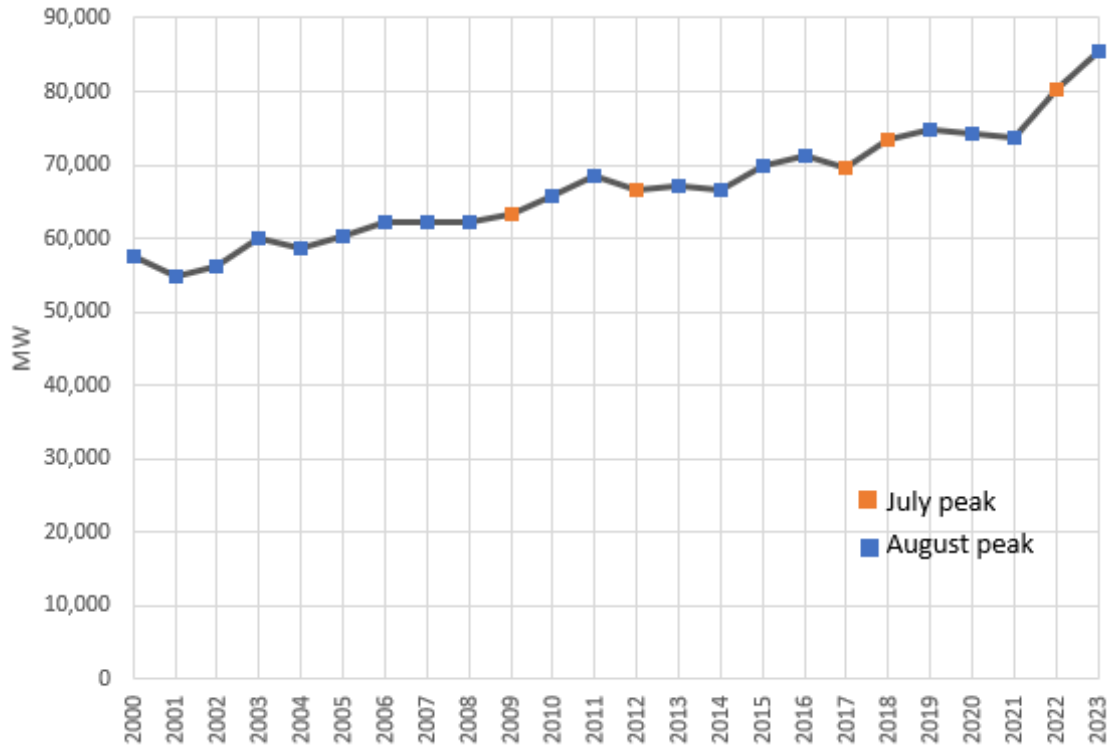


Figure 11 - ERCOT System Peak Load, 2000-2023

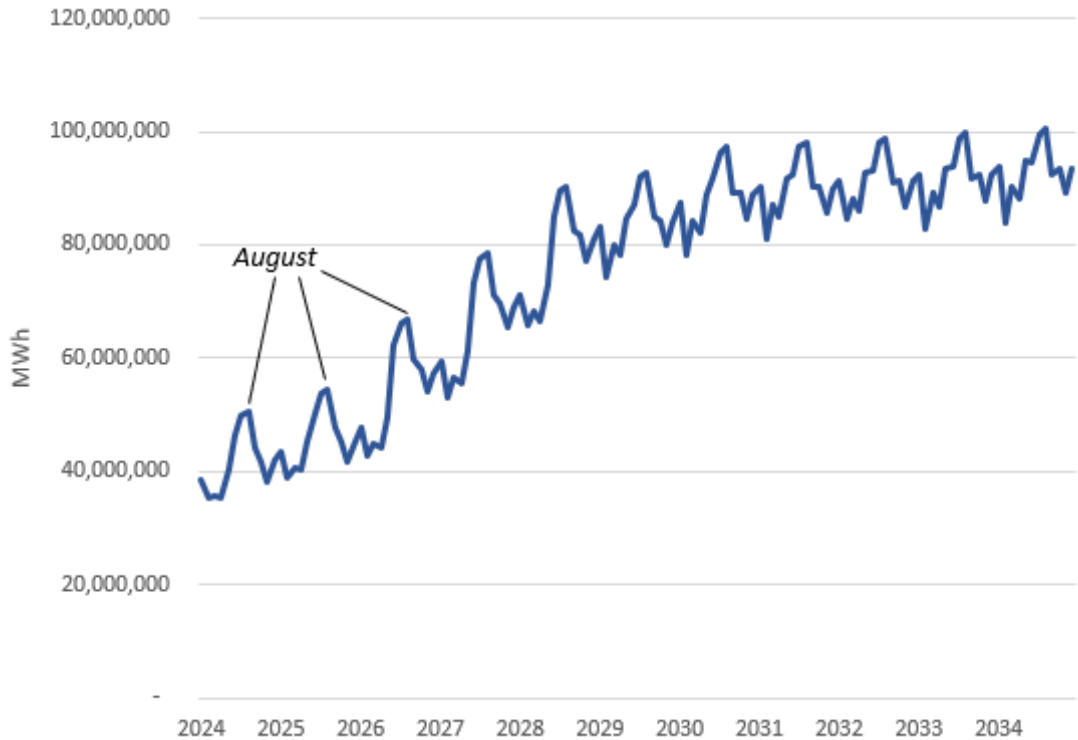


Figure 12 - ERCOT Monthly Load Forecast, 2024 - 2034

In terms of critical hydrology months, Lake Whitney’s pool elevation and the hydropower storage account bottom out annually in Late August-September according to baseline Period of Record modeling, and both SWPA and USACE Ft. Worth District staff confirmed that August is the generally the critical operating month for the project. This annual critical hydrologic period neatly intersects with the regional energy system’s annual peak load to clearly identify August as the critical month in which dependable capacity should be determined.

With the critical capacity period determined, the next step was to simulate the project’s maximum capability throughout the critical months of the period of record. Simulating maximum capability requires that appropriately extreme demand be assumed in the reservoir simulation model (RiverWare). For a project that is operated in a conventional “peaking” regime that maximizes hydropower production during high-value periods, assuming historical average hydropower demand may be sufficient for this purpose. However, for a lower capacity factor plant like Whitney Lake (where recent demand for energy generation has been minimal), assuming average demand would result in grossly understated capability – the RiverWare model would simply fail to dispatch the power plant at anywhere near its maximum capability. To ensure that the RiverWare model and subsequent modeling appropriately reflected capacity under critical conditions, each August in the period of record was separately simulated⁷ for each

⁷ The critical period capacity simulations were tied to the Period of Record simulations that inform the rest of this study; each August in the “capacity” simulations began with pool elevation and storage account levels from August 1st of the corresponding Period of Record simulations. However, the Period of Record simulations were not in turn affected by the August-only capacity simulations.

alternative assuming demand equal to four hours⁸ of output at the daily ending machine capability of the plant. This peaking demand assumption effectively prompts the RiverWare model to “attempt” to dispatch the plant at its machine capability for the days within each annual critical month. Factors that can limit or prevent this level of dispatch are insufficient energy (water) in storage, low operating head, or releases for other project purposes, all of which are impacted by the proposed alternatives. Importantly, the critical period capacity simulations ran for the entire month(s) of August, such that reservoir drawdown occurred over the course of subsequent days of peaking operation. This feature of the approach ensured that the analysis would capture the impacts to energy in storage of the reallocation scenarios.

The RiverWare model produces results with a daily periodicity, whereas the dependable capacity of a project is based on its sustained capability during the peak *hours* of critical periods. A final step was required to derive hourly results from the daily results of the RiverWare runs. This step took the daily simulated hydrology from RiverWare – reservoir elevation and total flow available to the powerhouse – and plant-specific data on generating unit efficiency, tailwater rating, and operating constraints⁹ as inputs to a suite of hydropower modeling tools used by HAC for numerous study applications. Brief descriptions of these models follow, and full documentation of SCE-TOM is included in Appendix A.

SCE-TOM

The optimal operation of the project is modeled by the Shuffled Complex Evolutionary Turbine Optimization Model (“SCE-TOM”). SCE-TOM takes numerous possible combinations of hydraulic head and water flow through the powerhouse and optimizes the dispatch of generating units to maximize power output. The resulting matrix of maximum power associated with combinations of head and flow – called a powerhill – standardizes the simulated dispatch of units within the plant in a way that generally reflects actual operations, allowing for comparison of plant performance across study alternatives. For each alternative, a powerhill reflecting each possible combination of units available is produced. For calculating dependable capacity, both units are assumed to be available.

Energy Linking Model (ELM)

The project-specific powerhills produced by the SCE-TOM model are combined with the simulated critical period hydrology produced by the RiverWare model are combined in the Energy Linking Model (ELM). The ELM simulates plant output given available hourly available water flow, operating head, and project flow constraints. As a preliminary step, daily total flows from RiverWare are shaped into hourly values such that flow in a first target hour is maximized (subject to flow constraints), then a second hour, and so on until the daily total is exhausted. The ELM then runs through each hour of the resulting hydrologic time series and calculates hourly energy output using a powerhill developed in SCE-TOM.

⁸ The four hours here reflects typical contractual and operational requirements of generating resources; power markets and participants typically require that firm capacity be sustained for several consecutive hours, rather than counting on a generator’s instantaneous maximum output.

⁹ Plant operating characteristics were provided by the Hydroelectric Design Center (HDC)

In many applications, the ELM is used to simulate project operations stochastically, sampling different historical years' hydrology, different possible unit availability scenarios, and different market price forecasts multiple times in order to evaluate a range of potential outcomes. For the purposes of this study, RiverWare-simulated hydrology for the critical months (August) of the Period of Record (1939 – 2022) are used in place of historical observations, and full availability is assumed.

Dependable Capacity Impacts

Once hourly peak capability during each critical month in the Period of Record is modeled by the ELM, dependable capacity was then determined by the 85% exceedance sustained output for each alternative. In other words, the dependable capacity of the project is its sustained capability to serve load under 85% of possible hydrologic conditions in the sample of simulated August days. Figure 13 illustrates these results in the form of exceedance curves. Each point along a curve represents the 4-hour sustained output of the plant on an August day; there are 2,604 such 4-hour periods in the 84-year simulated sample. Table 11 summarizes these results.

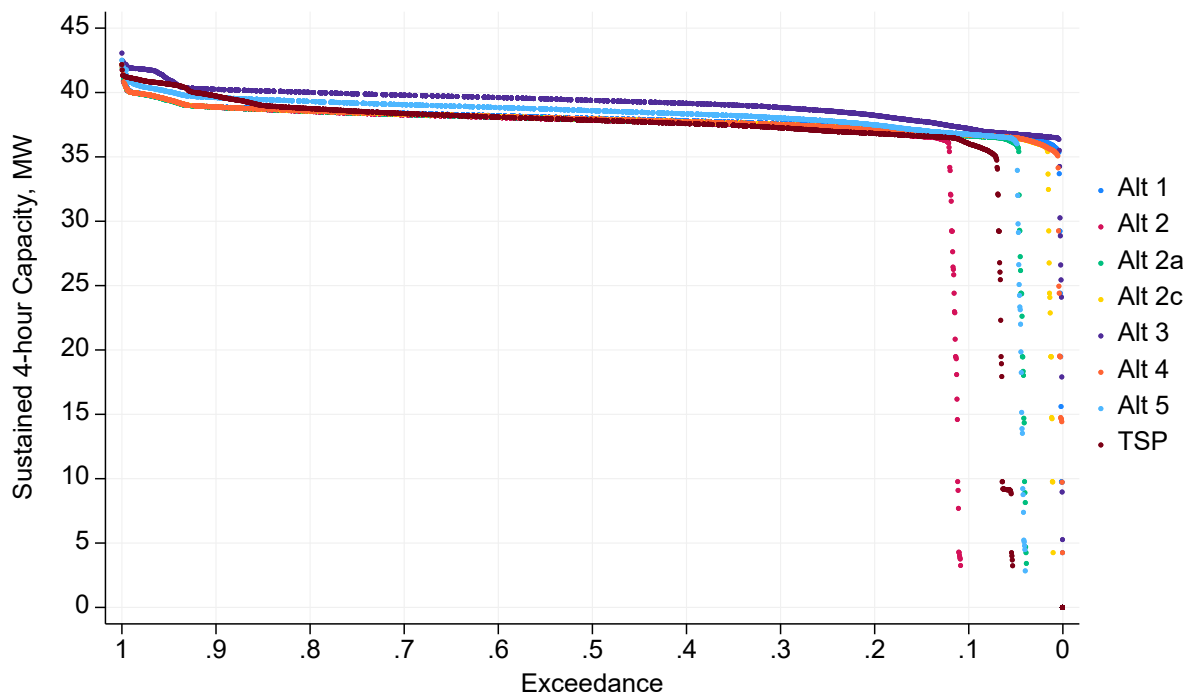


Figure 13 - Dependable Capacity

Table 11 - Dependable Capacity

Capacity at Indicated Criterion

| | 85% Exceedance | 90% Exceedance | 95% Exceedance |
|-------------------------|----------------|----------------|----------------|
| Alt 1 (Baseline) | 36.9 | 36.74 | 36.54 |
| Alt 2 | 36.6 | 0 | 0 |
| Alt 2a | 36.8 | 36.62 | 35.99 |
| Alt 2c | 36.9 | 36.71 | 36.48 |
| Alt 3 | 37.8 | 37.2 | 36.77 |
| Alt 4 | 36.9 | 36.72 | 36.49 |
| Alt 5 | 37.1 | 36.75 | 36.19 |
| TSP | 36.6 | 36.04 | 0 |

The impacts of the reallocation alternatives are generally small and negative at the 85% exceedance criterion, with small positive impacts for Alternatives 3 and 5. However, Figure 13 and Table 11 indicate that the results are sensitive to the specified availability criteria, particularly Alternatives 2 and 6, where extreme impacts begin and quickly mount between the 85% and 90% exceedance levels, and 90% and 95% exceedance levels, respectively. This sensitivity can be seen at the right side of in Figure 13 as the exceedance curves for these alternatives drop precipitously near the 0.1 (90%) level, and in Table 11 as dependable capacity drops to zero in the 90% exceedance and 95% exceedance columns.

Hydropower Benefits Impacts Summary

Table 12 collects the previously presented results. Monetary values are based on the replacement costs of power as represented by market prices.

Table 12 – Average Annual Hydropower Benefits Summary

| | Energy | Reserves (RRS) | Total NED Benefits | Benefits Change from Baseline | Benefits % Change from Baseline | Dependable Capacity (85% Exceedance; MW) | Dependable Capacity % Change from Baseline |
|-------------------------|-------------|----------------|--------------------|-------------------------------|---------------------------------|--|--|
| Alt 1 (Baseline) | \$2,051,991 | \$4,686,168 | \$6,738,159 | n/a | n/a | 36.9 | n/a |
| Alt 2 | \$2,200,544 | \$4,532,770 | \$6,733,314 | -\$4,845 | -0.1% | 36.6 | -1.0% |
| Alt 2a | \$2,142,905 | \$4,590,497 | \$6,733,402 | -\$4,757 | -0.1% | 36.8 | -0.4% |
| Alt 2c | \$2,088,834 | \$4,647,672 | \$6,736,506 | -\$1,654 | 0.0% | 36.9 | -0.1% |
| Alt 3 | \$2,188,152 | \$4,834,511 | \$7,022,663 | \$284,504 | 4.2% | 37.8 | 2.2% |
| Alt 4 | \$2,081,627 | \$4,654,968 | \$6,736,595 | -\$1,564 | 0.0% | 36.9 | -0.1% |
| Alt 5 | \$2,214,025 | \$4,670,040 | \$6,884,066 | \$145,906 | 2.2% | 37.1 | 0.3% |
| TSP | \$2,371,258 | \$4,358,261 | \$6,729,520 | -\$8,640 | -0.1% | 36.6 | -0.9% |

Additional Sensitivity Analysis

Fort Worth district completed additional modeling intended to capture the sensitivity of the results of the tentatively selected plan to (1) assumed future hydrologic conditions, and (2) assumed water supply

customer water demands. These two sensitivities are referred to as the “15% sensitivity” (referring to an assumption that local inflows to all reservoirs in the regional system are 15% drier than in the period of record) and the “full-use sensitivity” (referring to an assumption that the water supply customer utilizes its entire storage allocation at least once in the period of record)¹⁰. It is important to note that results of the 15% sensitivity are not directly comparable to the study baseline or any other alternative given that it utilizes different assumed hydrology by definition. Nevertheless, the results of these two sensitivities are presented below alongside the baseline and TSP.

Generally, the full-use sensitivity results in larger impacts than the unmodified TSP run relative to the baseline – roughly 1.6 times larger positive changes to energy generation and 1.6 times larger negative changes to reserves provision. Because a plant’s peaking capability does not have a one-to-one relationship with either of the sensitivities’ assumptions, relative changes to dependable capacity are not as pronounced at the 85% exceedance criterion, but do mount between the 85% and 90% levels.

Monetary impacts would be proportional to these results.

Table 13 - Sensitivity Analysis - Average Annual Generation

| | Average Annual Generation (MWh) | Change from Baseline | % Change from Baseline |
|---------------------------------|--|-----------------------------|-------------------------------|
| Alt 1 (Baseline) | 48,098 | - | - |
| TSP | 52,409 | 4,311 | 9.0% |
| TSP 15% Sensitivity | 44,987 | n/a | n/a |
| TSP Full Use Sensitivity | 55,034 | 6,936 | 14.4% |

Table 14 - Sensitivity Analysis - Average Annual RRS Provision

| | Average Annual RRS (MWh) | Change from Baseline | % Change from Baseline |
|---------------------------------|---------------------------------|-----------------------------|-------------------------------|
| Alt 1 (Baseline) | 315,866 | - | - |
| TSP | 304,893 | (10,972) | -3.5% |
| TSP 15% Sensitivity | 307,712 | n/a | n/a |
| TSP Full Use Sensitivity | 298,082 | (17,784) | -5.6% |

¹⁰ Full descriptions of these sensitivities and related RiverWare modeling can be found in the Hydrology and Reservoir Simulation Report attached to this study.

Table 15 - Sensitivity Analysis - Dependable Capacity

| | Dependable MW (85% Exceedance) | Change from Baseline | % Change from Baseline |
|---------------------------------|---|---------------------------------|---------------------------------------|
| Alt 1 (Baseline) | 36.9 | - | 0.0% |
| TSP | 36.6 | (0.33) | -0.9% |
| TSP 15% Sensitivity | 37.1 | n/a | n/a |
| TSP Full Use Sensitivity | 37.2 | 0.23 | 0.6% |

Power Marketing Administration Impacts

HAC’s hydropower analyses for water storage reallocation studies calculate both the impacts to NED benefits and (separately) the financial impact to the PMA’s revenues. This is because the PMAs are responsible for repayment of projects’ hydropower-specific costs and a portion of joint costs; if a water storage reallocation reduces the ability of the project to produce power, the PMA’s revenue and thus its ability to repay its obligations will likewise decrease. HAC’s calculation of PMA revenues foregone thus provides an estimate of the credit due to the PMA against its obligations. USACE guidance on estimating the revenue impacts of water storage reallocations is reflected in the following from EM 1110-2-1701:

“Revenues foregone to hydropower are the reduction in revenues accruing to the U.S. Treasury as a result of the reduction in hydropower outputs based on the existing rates charged by the power marketing agency.”

“The Corps does not market the power it produces; marketing is done by the Federal power marketing agencies (Southeastern Power Administration, Southwestern Power Administration, Western Area Power Administration, Bonneville Power Administration, Alaska Power Administration) through the Secretary of Energy. The rates are set by the marketing agency to: (a) recover costs (producing and transmitting) over a reasonable period of years (50 years usually); and (b) encourage widespread use at the lowest possible rates to consumers, consistent with sound business principles.”

Financial value to the power marketing agency is usually materially different from NED benefits for two primary reasons. The first is that NED benefits are based on economic value – replacement cost, society’s willingness to pay, and other related concepts. Foregone power from USACE hydroelectric dams must be replaced by system participants, and the market prices of energy and capacity represent the marginal cost to do so. The economic value of energy and capacity can be thought of as the avoided cost of having to purchase replacements at market prices. Conversely, the federal government does not charge power customers a market-determined price. Rather, federal power rates are based on the government’s cost of production and are often substantially lower than market prices. Because PMAs sell power at cost-based rates, rather than market prices, the revenue value of hydropower and the economic value of hydropower are different concepts.

The second reason that NED benefits can differ from PMA revenue is that the way in which PMA’s sell power reflects a bilateral agreement between specific parties and does not necessarily reflect its value to the entire energy system. A PMA’s contract with a power customer may be structured in a way that suits the PMA’s operating strategy and a specific customer’s purposes and may rely on contract terms and definitions that diverge from those used in the Corps hydropower analyses. This can be particularly true with matters of firm or dependable capacity, where minor differences in assumptions or definitions can drive significant discrepancies in calculated revenue and economic value.

Whereas the accounting of megawatt-hours of energy is reliably independent of individual entity’s perspectives, the accounting of capacity is not. Therefore, the capacity revenue estimates below should be interpreted as rough approximations of the actual financial impact to the Power Marketing Administration based on changes to dependable capacity. Actual impacts to the PMA will be driven by changes to the amount of capacity actually marketed to its customers.

Revenues foregone estimates for each of the study alternatives are based on rates which took effect under SWPA’s Rate Schedule P-23 on June 1, 2025¹¹:

Capacity: \$5.30/kW-month of Peaking Billing Demand

Energy: \$12.80/MWh

SWPA does not charge a volumetric rate associated with the Responsive Reserve Service provided by the project to its customers. Impacts to RRS provision are thus excluded from these revenue calculations.

Table 16 - PMA Revenue Impacts

| | Energy (MWh) | Energy Revenue | Dependable Capacity (MW) | Capacity Revenue | Total Revenue | Revenue Change from Baseline | Revenue % Change from Baseline |
|-------------------------|--------------|----------------|--------------------------|------------------|---------------|------------------------------|--------------------------------|
| Alt 1 (Baseline) | 48,098 | \$615,656 | 36.94 | \$2,349,384 | \$2,965,040 | \$0 | 0.0% |
| Alt 2 | 50,082 | \$641,046 | 36.58 | \$2,326,488 | \$2,967,534 | \$2,494 | 0.1% |
| Alt 2a | 49,279 | \$630,766 | 36.8 | \$2,340,480 | \$2,971,246 | \$6,206 | 0.2% |
| Alt 2c | 48,465 | \$620,355 | 36.89 | \$2,346,204 | \$2,966,559 | \$1,519 | 0.1% |
| Alt 3 | 50,106 | \$641,352 | 37.76 | \$2,401,536 | \$3,042,888 | \$77,847 | 2.6% |
| Alt 4 | 48,404 | \$619,565 | 36.9 | \$2,346,840 | \$2,966,405 | \$1,365 | 0.0% |
| Alt 5 | 50,347 | \$644,439 | 37.06 | \$2,357,016 | \$3,001,455 | \$36,414 | 1.2% |
| TSP | 52,409 | \$670,833 | 36.61 | \$2,328,396 | \$2,999,229 | \$34,188 | 1.2% |

¹¹ See <https://www.energy.gov/swpa/rate-schedule-actions> for rate terms and definitions

A final caution regarding the revenue estimates above requires discussion. As the rightmost column illustrates, changes to revenue as a result of the proposed reallocation would be positive, because under these alternatives generation increases due to water supply releases through the powerhouse. However, as noted, SWPA and its customers utilize this project primarily for reserves capacity rather than energy. Thus, these changes may not be viewed as positive by these parties regardless of the minor increases in energy produced and revenues collected. Longer-term impact to SWPA and hydropower utilization at the project may be impacted in ways that are neither marginal nor captured by these estimates.

Risk, Uncertainty, and Further Considerations

This report summarizes an analysis of the hydropower impacts resulting from several proposed reservoir reallocation scenarios. The estimates presented are subject to data limitations, modeling imperfections, and other constraints. While the intention of the approach taken is to accurately capture the physical and economic impacts being evaluated, the use of assumptions, proxies, and other simplifications warrants awareness. Further, specific uncertainty related to physical hydropower operations under the Tentatively Selected Plan requires further consideration. Below is a summary of these issues.

- **Energy and ancillary services prices and replacement value of hydropower.** The monetary values associated with simulated power production are based on forecasts provided by the EIA and a simple projection method used by USACE. While the underlying forecasts attempt to capture the uncertainty and volatility inherent in energy markets, history – particularly, recent history – have illustrated that actual energy prices can and do diverge significantly from expectations. Pronounced one-sided (upside) risk to energy values, and thus energy benefits, should be acknowledged
- **Dependable capacity benefits.** As noted above, the regional market into which Whitney’s output is sold is an “energy-only” market that in theory bundles the economic values of both energy and capacity into a single price per unit of energy. However, experiences in both ERCOT and other US markets tend to suggest that the value of capacity is not reliably embedded in energy prices. Thus, while additional “capacity benefits” over and above energy benefits are omitted from this analysis, it is likely that they are nonzero.
- **Hydropower operating regime uncertainty.** The users of Whitney’s hydropower undertook a major shift in operating regime from primarily energy production to primarily reserve capacity provision in the mid-2010’s. A rapidly changing market landscape almost certainly played a role in this decision. The market landscape in this region especially (and in the rest of the country more generally) remains in a state of rapid evolution, and while current operations are assumed to persist through the study horizon, deviations from this regime are possible and could substantially alter the estimates in this report.
- **Minimum reservoir elevation and risk to hydropower operations.** Perhaps the most important point of uncertainty in this analysis is the nature of the proposed reservoir reallocation in the Tentatively Selected Plan. In the TSP, the bottom of the conservation pool is lowered from 520’ to 512’. Since the turbine units in the Whitney powerhouse were installed, they have not been operated under a forebay below 520’. Due to limitations in their engineering and installation, it is not certain that the turbines can be safely operated at corresponding low operating heads. If it is found that the turbines cannot safely operate at forebay elevations implied by the TSP, they

would be rendered indefinitely unusable under these critical hydrologic conditions. This would represent a major impact to the hydropower project purpose that has not been simulated or evaluated in this hydropower analysis. The Hydroelectric Design Center was engaged to evaluate this situation, but HDC’s conclusion was that substantial uncertainty remains regarding the minimum safe operating forebay elevation. HDC’s analysis is summarized in the attached Appendix B below.

Appendix A. Additional Model Documentation

Shuffled Complex Evolutionary – Turbine Optimization Algorithm

The SCE-TOM was developed by the Hydroelectric Design Center (HDC) in 2015 to aid in calculating economic benefits of turbine replacements and uprates across the USACE fleet. The two main motivations of this software development was to standardize the turbine dispatch across the units when comparing across alternatives, and to utilize the breadth of the entire turbine efficiency hill curves. Since its development the SCE-TOM has been used in a number of uprate studies across the USACE fleet and is now considered the standard approach to evaluated alternatives.

The SCE-TOM model utilizes the shuffled complex evolutionary algorithm (SCE-UA). This algorithm was first developed in 1992 by Duan et al as an efficient and effective method to calibrate rainfall-runoff models. Like a hydropower facility with several units that could be turned on or off, rainfall-runoff models usually consist of several parameters that need calibrated.

The basic procedure of the SCE-UA algorithm involves, first, randomly searching through the feasible space through a number of solution sets or guesses. The solution sets are then ranked according to their objective function scores. Lower ranking scores “evolve” by being manipulated to reflect the higher scoring objective functions within a complex (a subset of the total solution sets). After this evolution step the procedure is repeated until a maximum set of iterations. The SCE-UA algorithm optimizes the function only in the statistical sense (e.g., percent of time) where the performance success is generally dependent on a number of iterations or objective function computations. More discussion of this algorithm can be found in the paper *Effective and Efficient Global Optimization for Conceptual Rainfall-Runoff Models* (Duan et al 1992).

The goal of optimal hourly unit dispatch is to distribute the available powerhouse flow among the units to maximize generation. Unit efficiency is determined by unit and alternative-specific hill curves – lookup tables that associate efficiency as a function of flow and head. From these, generation is determined using the standard hydropower equation:

$$Power(MW) = \frac{Q(cfs) * Head(feet) * efficiency}{11,800}$$

To maximize generation using the SCE-UA algorithm the following objective function is developed:

$$MAX \left[\sum_{i=1}^n \left(P(H_t, Q_t^i, e_t^i) - w_1 |Q_t^i - Q_{t-1}^i| - w_2 F(H_t, Q_t^i) \right) \right]$$

Where,

n = Number of units

H_t = Head at time t

Q_t^i = Flow through turbine at time t

e_t^i = Efficiency of turbine i at time t

$P(H_t, Q_t^i, e_t^i)$ = Power (MWH) for unit i at time t with efficiency e

$$F(H_t, Q_t^i) = \begin{cases} 1 & H_t, Q_t^i \in \text{Cavitation Zone} \\ 0 & H_t, Q_t^i \notin \text{Cavitation Zone} \end{cases}$$

w_1 = Weighted penalty coefficient for unit flow changes

w_2 = Weighted penalty coefficient for cavitation zones

The objective function is the summation of the power generation across all the units combined with two negative penalty functions. The first penalty function $|Q_t^i - Q_{t-1}^i|$ seeks to minimize extreme changes in flow distribution between time intervals for particular units. For example this penalty function reduces the likelihood of a situation where a particular unit running at full capacity is somehow turned off and replaced with another unit running at full capacity. The second penalty function, $F(H_t, Q_t^i)$ seeks to minimize the time that units are operating in the cavitation or rough zone.

SCE-TOM Inputs

There are three major inputs to the SCE-TOM: powerhouse configuration, turbine efficiency (“hill”) curves, and turbine flow limitations.

Powerhouse Configurations: The powerhouse configuration describes the powerhouse setup under various alternative unit sizes.

Turbine Efficiency (“Hill”) Curves: A turbine efficiency (hill) curve describes how the efficiency of the turbine changes as a function of both the head and the flow going through the turbine. The name “hill” is derived from the fact that the contour plot of this curve is similar to a topographical map of a mountain leading to a peak.

Turbine Flow Limitations: Turbine flow limitations represent the maximum and minimum amount flow that can enter a turbine as a function of head. In general, these limitations follow either generator of

cavitation limits. The SCE-TOM model assumes the upper limits are hard (model will not allow flow past this point) and the lower limits are soft (model will allow flow but are penalized in the objective function).

SCE-TOM Outputs

For a given head and flow relationship the SCE-TOM produces the optimal powerhouse output in MWh. In addition, the SCE-TOM produces unit specific data including turbine efficiency, unit flow, unit power, and unit net head. These inputs are used to calculate metric such as reserves and operational complexity described above. In general the SCE-TOM is not run on an individual head-flow relationship, but on a series of head flow relationships that will make a matrix of power outputs called a power hill.

To speed up the benefit analysis of a turbine configuration across a number of different hydrological scenarios and unit availability scenarios the SCE-TOM is run across a grid of head and flow relationships. Figure 14 illustrates the mesh sizing used for this analysis.

$\Delta h=1$

| | | | | |
|-----------------------------------|---------------|-------------|-------------|------------|
| | <i>0</i> | → | → | <i>120</i> |
| | <i>0</i> | $P_{q1/h1}$ | $P_{q1/h2}$ | ... |
| $\Delta q=1000$ | ↓ | $P_{q2/h1}$ | $P_{q2/h2}$ | ... |
| | ↓ | ... | ... | ... |
| | <i>12,000</i> | ... | ... | ... |

Figure 14 - Powerhill Mesh Sizing

Once the analysis is complete, the resulting power output for each head and flow relationship is combined to form a matrix called a power hill curve. Along with power hill matrix, unit specific data is also stored to compute reserves and operational complexity metrics. Power hills are also developed for configurations with units made unavailable. This is to compute benefits associated with reliability.

Appendix B. Hydroelectric Design Center Forebay Analysis

[see attachment]



MEMORANDUM FOR THE RECORD

DATE OF REPORT: 4 April 2025

SUBJECT: Whitney Low Head Operation – Revisiting Forebay Analysis

PROJECT: Whitney Powerhouse

REPORT PREPARED BY: Dan Patla, Hydroelectric Design Center
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503-816-4760

1.0 Executive Summary

The Hydroelectric Design Center (HDC) was requested to evaluate Whitney operational functionality at low heads due to water reallocation studies. Since the units have been installed in 2015, they have not been operated under a forebay of 520 ft. However, if water resources were diverted away from hydropower production, it is anticipated that forebays may drop.

The Whitney hydraulic turbines were designed using Computational Fluid Dynamics (CFD), but to reduce overall project costs, the design did not undergo a model test. This decision makes analysis at lower heads less certain and requires more engineering judgement.

The concern for low head operation is a pressure side inlet cavitation. Two-unit operation will impact the head due to the increase in tailwater elevation with more flow in the downstream channel.

Analysis and conclusions are detailed in this document. This analysis is intended to supersede analysis prepared in September 2023.

In addition to the analysis provided herein, factors that influence the risk profile for the operation of the turbines in unknown situations is included. Bottom line is that due to a variety of factors, the turbines at Whitney Powerhouse should be considered at a higher risk for operational issues in uncertain operating conditions.

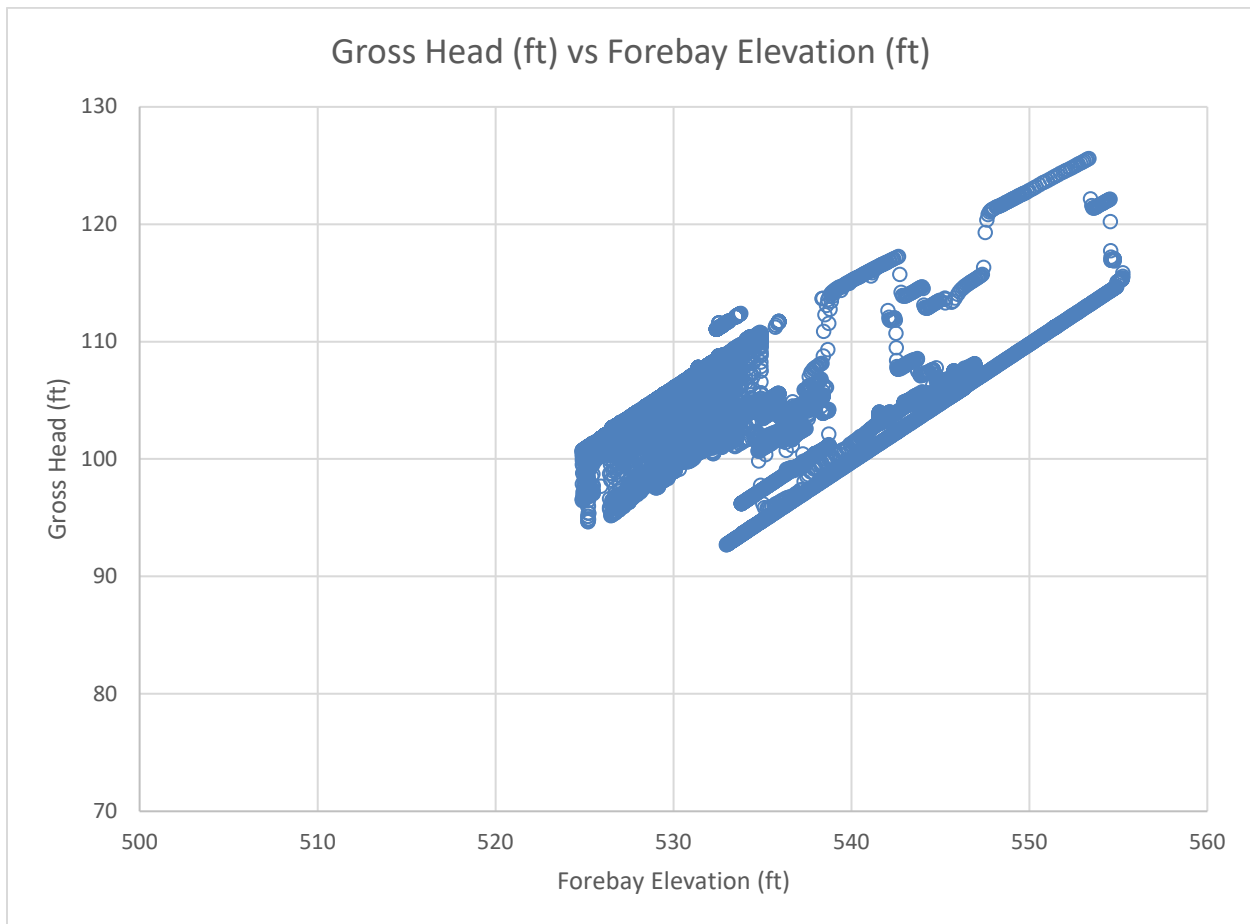
2.0 Data Analysis

In September 2023, forebay analysis was conducted in two separate methodologies that seemed to correlate. Each of these methodologies will be discussed separately.

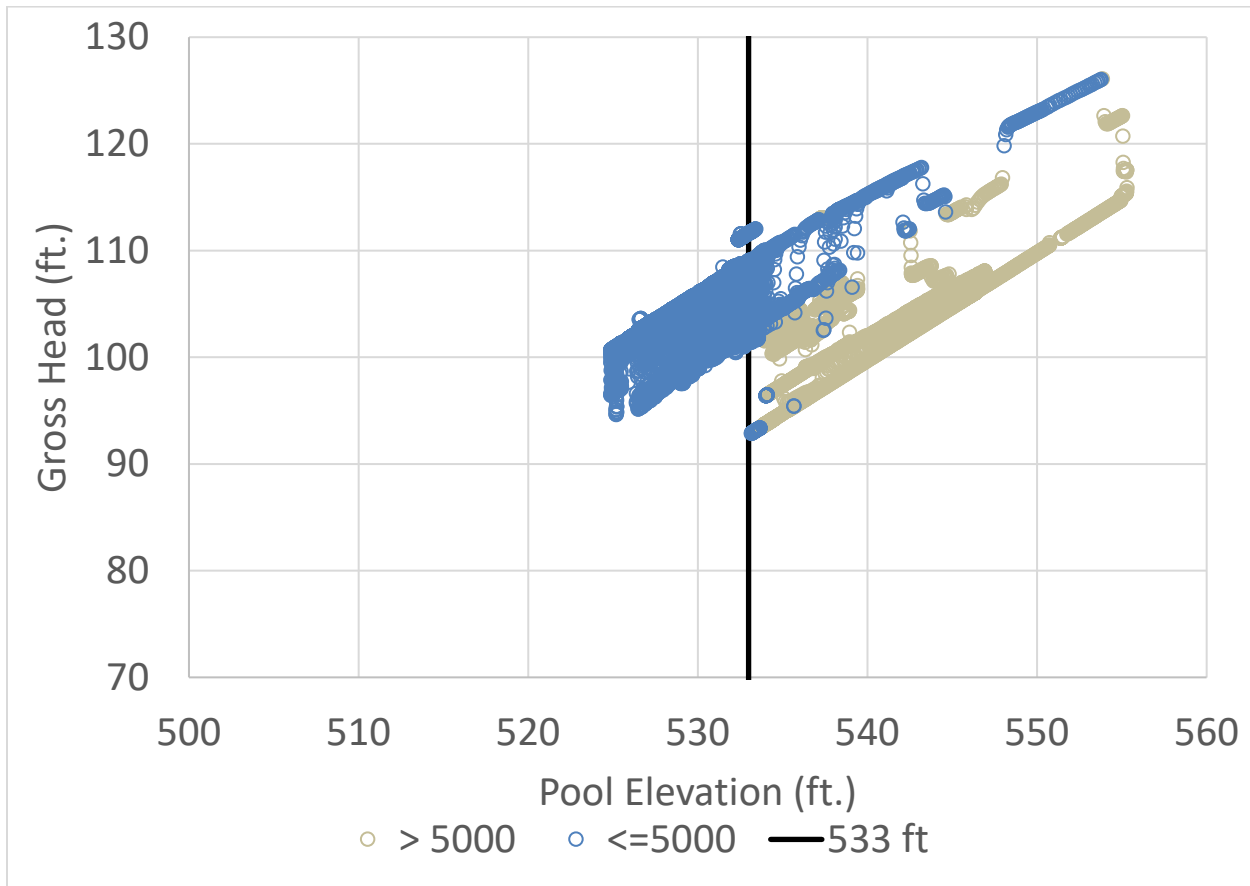


2.1 Gross Head Versus Forebay Elevation

The first methodology included a graphing of the gross head versus the Forebay elevation. A graph of this analysis is shown below:



A subset of this data was provided to Brazos River Authority and their hired engineering firm, Hazen. Hazen examined the data and determined that the inclusion of spill data was influencing the analysis. A graph created by Hazen highlighting times of spill is shown below:



As Hazen points out, the influence of the spillway can impact this methodology by including tailwater elevations that are not seen as applicable to the times in which the forebay may be lowered. Due to this consideration, this form of analysis was less robust than the second methodology that will be discussed next.

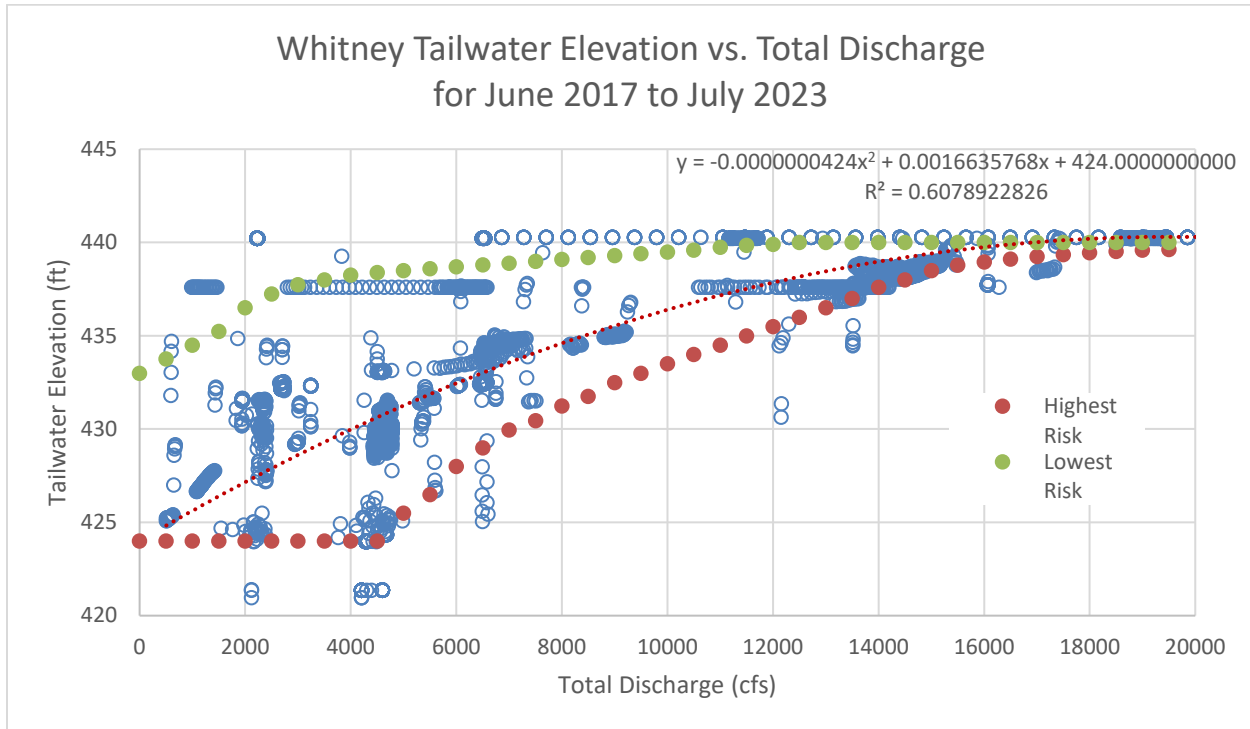
2.2 Tailwater Versus Discharge Curve

A more robust analysis methodology of determining minimum forebay elevations would be to take into account the anticipated tailwater rise based on two units operating. At that point, the minimum head the turbines were designed could be added to it, along with the anticipated head loss due to friction added.

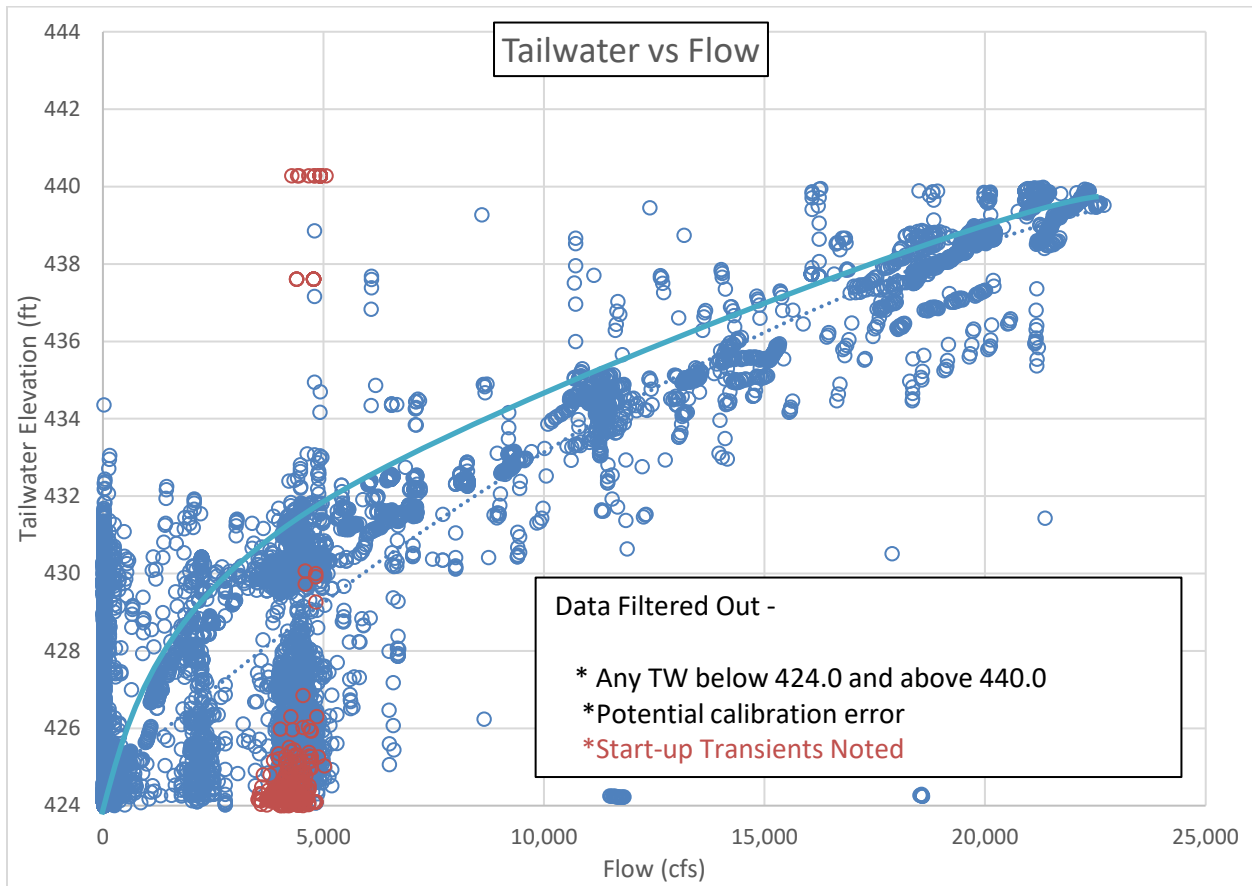
The Toshiba runners were designed for a minimum head of 79 ft. Based on a Pressure-Time test in accordance with PTC-18 in 1954, the head loss at 4500 cfs is estimated to be 1 ft. Therefore 80 ft will be added to the tailrace elevation with two units operating, which for estimating purposes will be considered flows between 3500 cfs to 5500 cfs.



In the December 2023 analysis, the dataset was less than ideal and different risk lines were assigned, as shown below.

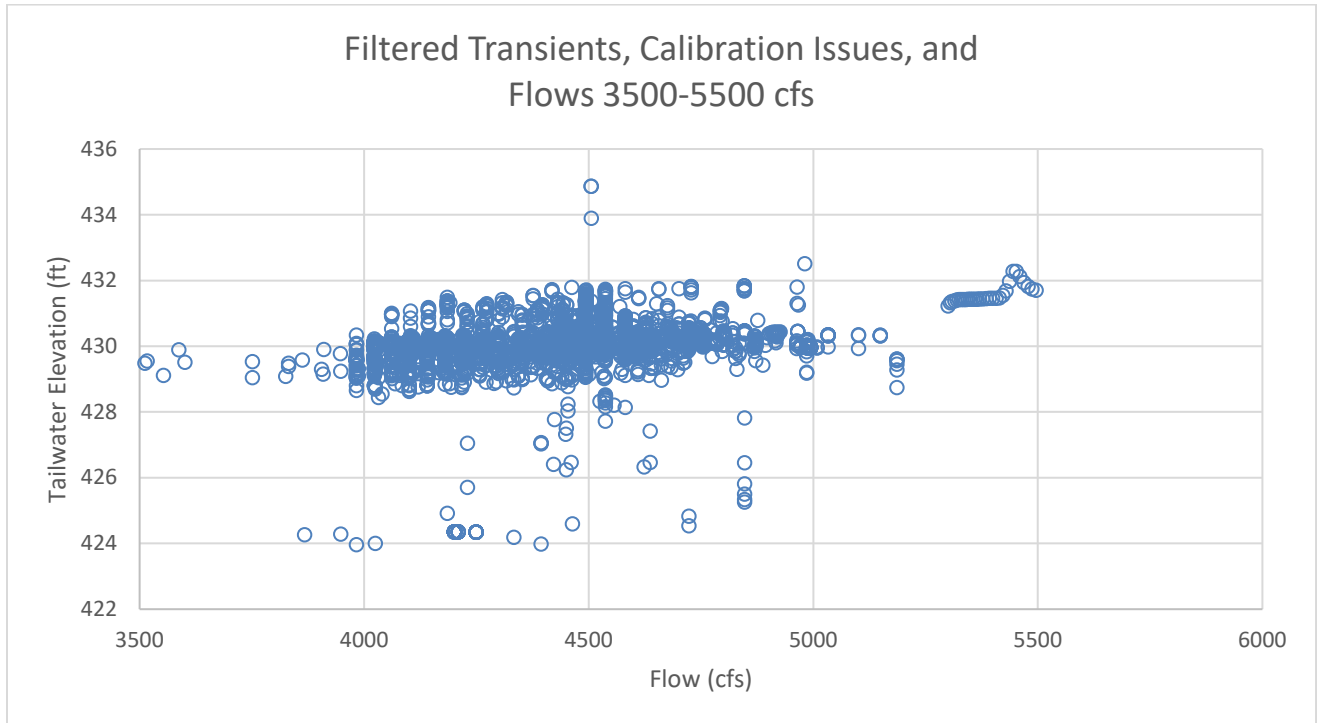


For whatever reason, the Hazen dataset had more data, and so concern with filtering bad data out was lessened. Using the dataset provided by Hazen, the tailwater elevation versus flow appears below:

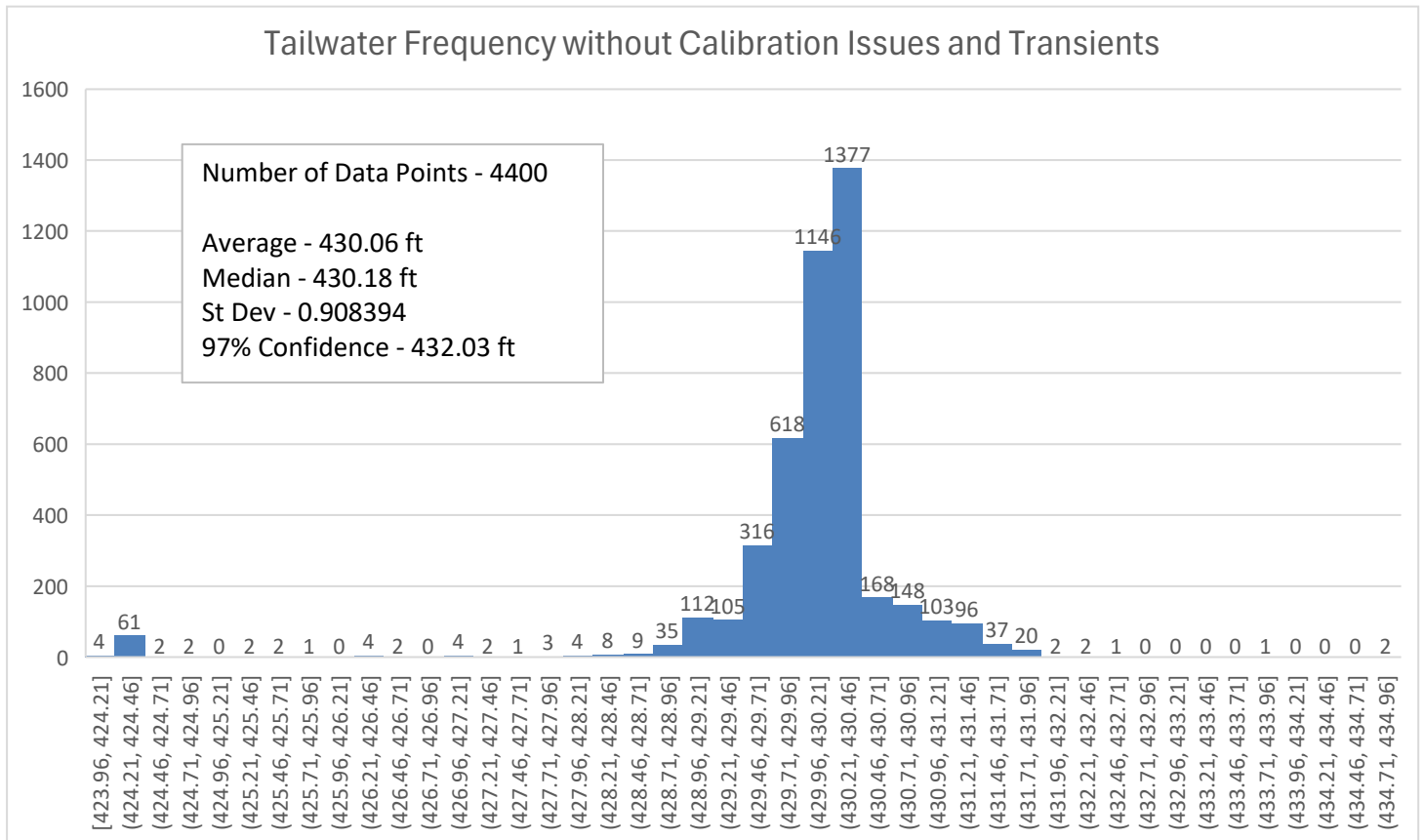


Note that the solid blue line added in the image above was a visual approximation added; detailed analysis to follow.

In order to appropriately inform the basis of what tailwater elevation would be an acceptable risk level for turbine operation cavitation in a cavitation free regime, the data was analyzed for the flows between 3500 cfs and 5500 cfs. This snapshot is shown below:



A histogram of the this filtered dataset is shown below:



When HDC prepares specifications for a new turbine runner, the cavitation guarantee allows for as much as 3% of operation outside of the range specified. While this specific verbiage is not present in the Whitney Contract, it serves as an appropriate risk tolerance for what deviations from the anticipated head that could be attributable to the tailwater variation.

Thus, using a 97% confidence interval, the water elevation that best describes this risk profile is 432 ft.

When the 80 ft for the minimum head of the turbine and the anticipated head loss is applied to the 97% confidence interval of the tailwater data, the minimum forebay elevation for turbine runner operation becomes 512 ft.

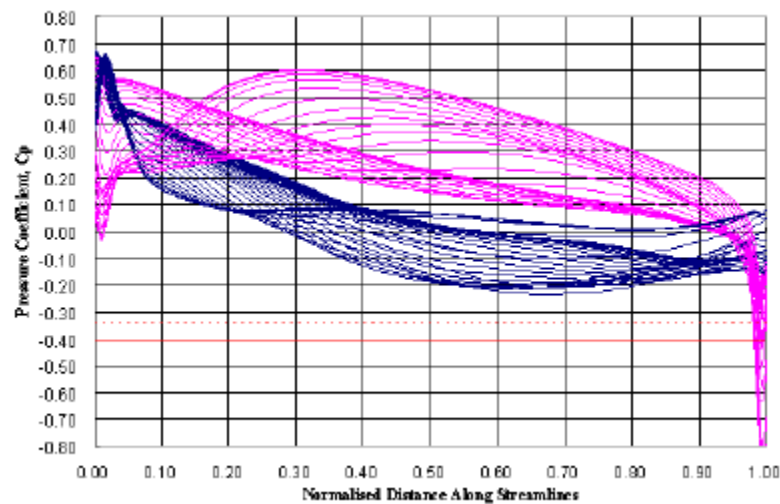
3.0 Factors Influencing Risk Profile

3.1 Design Technique



The Whitney turbine was designed using CFD and was not model tested. CFD in 2008 was considered acceptable for predicting the incipient of outlet flow cavitation caused by high flows. It was not considered as efficacious in determining inlet flow cavitation, particularly on the pressure side. The pressure side inlet flow cavitation is a function of low head, so immediately pertinent to the task at hand. The Toshiba contract is unique for the Corps of Engineers in this respect, as all turbine runner replacements since 1990 were model tested.

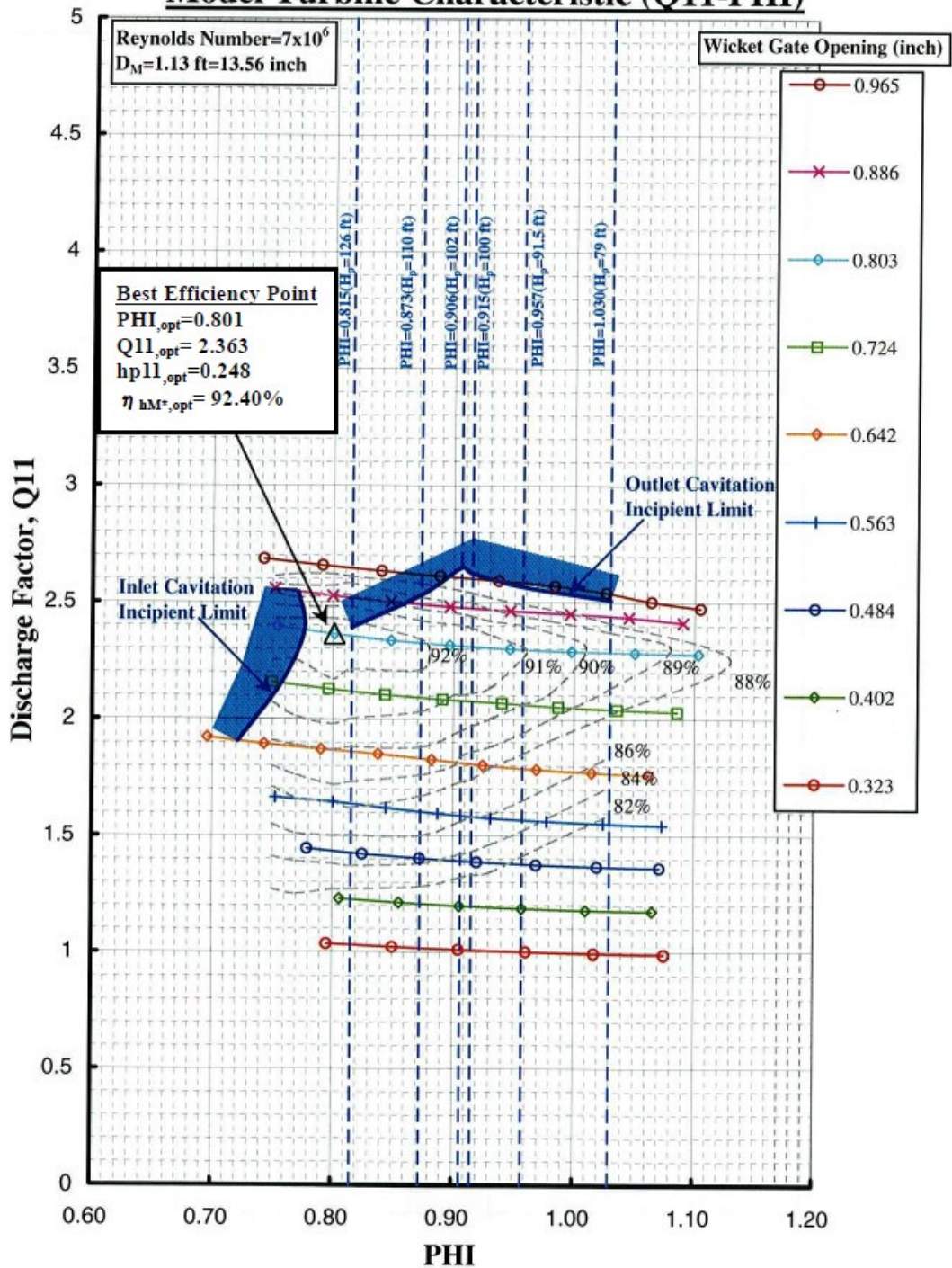
The Whitney CFD report explored heads down to 79 ft. Blade pressures were calculated using the Navier-Stokes equations. A sample of the analysis for the outlet flow cavitation is provided below:



However, the CFD report did not adequately address concerns for pressure side inlet cavitation, as can be seen on the model hill chart on the next page.



Model Turbine Characteristic (Q11-PHI)





3.2 Contract Exceptions

The proposal to the contract provided by Toshiba took exceptions from some of the specifications, including performance guarantees that influence cavitation. As the proposal was accepted by the Government at time of award, the performance guarantees would be considered deferred to Toshiba's proposal rather than the specifications. This is to say that the contract specifications alone cannot be utilized to determine the performance of the Whitney Powerhouse turbine runners.

3.3 Field Modifications

Additionally, during the first effort to commission the new Toshiba units, it was noted that the blades vibrated at a frequency that was audible. This phenomenon is often colloquially called "singing blades" and is caused by von Karman vortices being shed from the trailing edge of the Francis runner blades.

To address this issue (as well as other construction mistakes), the unit was disassembled and the blades were modified in the field. Details on the modification and the effects can be seen in the appendix.

3.4 Lack of Performance Test

Partially due to difficulties to assess the exceptions taken by Toshiba in the proposal phase and partially due to cost considerations, a performance test was not pursued on the Whitney turbines. This includes the field modifications.

3.5 Risk Profile Conclusion

Due to several factors (CFD Design, Field Modifications, etc.) the Toshiba runners have a higher uncertainty to performance in unusual and untested conditions. Therefore, a risk profile that is less accepting of risk appears more appropriate.



4.0 Conclusion

This evaluation of Whitney Powerhouse's operational functionality at low heads, prompted by potential water reallocation scenarios reveals a heightened risk for turbine operation under forebay elevations below 520 ft. Analysis utilizing tailwater versus discharge curves indicates a minimum acceptable forebay elevation of 512.0 ft to avoid cavitation damage to the turbine runners. However, considering the original turbine design relied on Computational Fluid Dynamics without model testing, coupled with accepted contract exceptions from Toshiba and subsequent field modifications, operating below this level introduces unacceptable uncertainty and potential for equipment damage. **Therefore, to ensure the continued safe and reliable operation of the Whitney Powerhouse turbines, all generation must cease when the forebay elevation reaches 512.0 ft. Upon reaching a forebay elevation below 520.0 ft, a formal monitoring operation must be initiated at the project. This monitoring will continue until operation down to 512.0 ft is determined to be acceptable.**

5.0 Appendices

Operational tables are provided in Appendix A. Details on the field modifications can be seen in Appendix B.



USACE
HYDROELECTRIC DESIGN CENTER



5.1 Appendix A – Extended Discharge Table

| Power (MW) | Head(ft) | | | | | | | | | | | | | | | | | | | | | | | |
|------------|----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| | 72.5 | 75 | 77.5 | 80 | 82.5 | 85 | 87.5 | 90 | 92.5 | 95 | 97.5 | 100 | 102.5 | 105 | 107.5 | 110 | 112.5 | 115 | 117.5 | 120 | 122.5 | 125 | | |
| 6 | 1215.0 | | | | | | | | | | | | | | | | | | | | | | | |
| 6.5 | 1351.7 | 1248.2 | 1281.4 | 1314.6 | 1283.9 | | | | | | | | | | | | | | | | | | | |
| 7 | 1455.7 | 1407.1 | 1361.7 | 1381.7 | 1350.1 | 1318.5 | | | | | | | | | | | | | | | | | | |
| 7.5 | 1521.6 | 1507.6 | 1423.4 | 1447.0 | 1415.0 | 1383.0 | 1351.0 | | | | | | | | | | | | | | | | | |
| 8 | 1623.0 | 1568.9 | 1518.3 | 1507.0 | 1471.9 | 1436.7 | 1401.5 | 1366.4 | | | | | | | | | | | | | | | | |
| 8.5 | 1726.3 | 1667.0 | 1613.2 | 1580.4 | 1543.2 | 1506.0 | 1468.8 | 1431.5 | 1398.8 | | | | | | | | | | | | | | | |
| 9 | | 1765.0 | 1667.4 | 1631.4 | 1597.3 | 1563.1 | 1529.0 | 1494.9 | 1462.7 | 1433.2 | 1403.7 | | | | | | | | | | | | | |
| 9.5 | | 1818.7 | 1760.1 | 1713.2 | 1672.2 | 1631.1 | 1590.0 | 1549.0 | 1512.0 | 1481.2 | 1450.3 | | | | | | | | | | | | | |
| 10 | | 1914.5 | 1852.7 | 1780.4 | 1736.9 | 1693.3 | 1649.8 | 1606.2 | 1568.6 | 1540.0 | 1511.4 | 1482.7 | 1461.0 | | | | | | | | | | | |
| 10.5 | | 2010.2 | 1900.1 | 1847.6 | 1802.5 | 1757.4 | 1712.3 | 1667.2 | 1627.4 | 1595.7 | 1564.0 | 1532.3 | 1508.9 | 1484.2 | | | | | | | | | | |
| 11 | | | 1990.6 | 1923.7 | 1875.5 | 1827.3 | 1779.1 | 1730.9 | 1688.3 | 1654.1 | 1619.9 | 1585.7 | 1562.0 | 1534.0 | 1506.0 | | | | | | | | | |
| 11.5 | | | 2081.1 | 1980.4 | 1933.0 | 1885.5 | 1838.1 | 1790.7 | 1747.7 | 1711.5 | 1675.3 | 1639.1 | 1614.4 | 1579.1 | 1543.9 | 1508.6 | | | | | | | | |
| 12 | | | 2171.5 | 2042.9 | 1993.6 | 1944.4 | 1895.1 | 1845.9 | 1801.9 | 1765.7 | 1729.5 | 1693.3 | 1659.0 | 1632.5 | 1606.1 | 1579.7 | 1581.5 | | | | | | | |
| 12.5 | | | | 2122.0 | 2071.6 | 2021.2 | 1970.8 | 1920.4 | 1874.6 | 1835.7 | 1796.9 | 1758.0 | 1719.8 | 1689.5 | 1659.1 | 1628.8 | 1630.0 | 1631.2 | 1632.4 | | | | | |
| 13 | | | | 2193.9 | 2141.8 | 2089.8 | 2037.7 | 1985.6 | 1937.2 | 1894.4 | 1851.5 | 1808.6 | 1774.7 | 1741.9 | 1709.0 | 1676.1 | 1678.4 | 1680.7 | 1683.0 | 1685.3 | | | | |
| 13.5 | | | | 2263.6 | 2209.5 | 2155.4 | 2101.3 | 2047.2 | 1997.4 | 1954.1 | 1910.8 | 1867.4 | 1827.9 | 1796.4 | 1764.9 | 1733.4 | 1733.8 | 1734.3 | 1734.7 | 1735.2 | 1735.6 | | | |
| 14 | | | | | 2277.3 | 2219.5 | 2161.8 | 2104.1 | 2052.0 | 2008.3 | 1964.6 | 1920.9 | 1886.9 | 1845.1 | 1803.4 | 1761.7 | 1766.1 | 1770.6 | 1775.1 | 1779.6 | 1784.0 | 1788.5 | | |
| 14.5 | | | | | | 2366.8 | 2276.0 | 2185.2 | 2113.7 | 2071.2 | 2028.8 | 1986.3 | 1949.2 | 1910.1 | 1871.0 | 1831.9 | 1831.8 | 1831.6 | 1831.5 | 1831.4 | 1831.2 | 1831.1 | | |
| 15 | | | | | | | 2319.1 | 2243.4 | 2171.9 | 2126.3 | 2080.6 | 2035.0 | 1991.2 | 1955.6 | 1920.0 | 1884.4 | 1884.8 | 1885.3 | 1885.7 | 1886.2 | 1886.6 | 1887.1 | | |
| 15.5 | | | | | | | 2362.2 | 2301.6 | 2237.3 | 2189.6 | 2141.9 | 2094.1 | 2053.1 | 2016.6 | 1980.2 | 1943.7 | 1943.2 | 1942.8 | 1942.3 | 1941.8 | 1941.3 | 1940.8 | | |
| 16 | | | | | | | | 2359.9 | 2294.3 | 2246.1 | 2197.9 | 2149.7 | 2102.8 | 2066.2 | 2029.7 | 1993.1 | 1993.0 | 1992.9 | 1992.7 | 1992.6 | 1992.5 | 1992.3 | | |
| 16.5 | | | | | | | | | 2357.6 | 2308.5 | 2259.4 | 2210.3 | 2162.1 | 2121.0 | 2079.9 | 2038.8 | 2038.3 | 2037.8 | 2037.3 | 2036.8 | 2036.2 | 2035.7 | | |
| 17 | | | | | | | | | | 2365.7 | 2314.3 | 2262.9 | 2214.5 | 2172.4 | 2130.3 | 2088.2 | 2086.9 | 2085.6 | 2084.3 | 2082.9 | 2081.6 | 2080.3 | | |
| 17.5 | | | | | | | | | | | 2374.8 | 2319.4 | 2280.3 | 2232.1 | 2183.8 | 2135.6 | 2135.6 | 2135.7 | 2135.7 | 2135.8 | 2135.8 | 2135.9 | | |
| 18 | | | | | | | | | | | | 2378.2 | 2320.7 | 2274.8 | 2229.0 | 2183.2 | 2183.1 | 2183.0 | 2182.8 | 2182.7 | 2182.6 | 2182.5 | | |
| 18.5 | | | | | | | | | | | | | | | 2336.1 | 2289.9 | 2243.8 | 2241.3 | 2238.7 | 2236.2 | 2233.6 | 2231.1 | 2228.6 | |
| 19 | | | | | | | | | | | | | | | | 2386.3 | 2335.8 | 2285.3 | 2285.3 | 2285.3 | 2285.3 | 2285.3 | 2285.3 | |
| 19.5 | | | | | | | | | | | | | | | | | 2387.5 | 2340.2 | 2339.3 | 2338.4 | 2337.5 | 2336.6 | 2335.7 | 2334.8 |
| 20 | | | | | | | | | | | | | | | | | | 2396.3 | 2397.1 | 2397.9 | 2398.7 | 2399.5 | 2400.2 | 2401.0 |
| 20.5 | | | | | | | | | | | | | | | | | | | 2442.7 | 2441.9 | 2441.0 | 2440.2 | 2439.4 | |
| 21 | | | | | | | | | | | | | | | | | | | | | 2498.7 | 2496.7 | 2494.7 | 2492.7 |
| 21.5 | | | | | | | | | | | | | | | | | | | | | | | 2547.5 | 2546.0 |
| 22 | | | | | | | | | | | | | | | | | | | | | | | | 2617.0 |
| 22.5 | | | | | | | | | | | | | | | | | | | | | | | | |

- Notes –
1. Based off the Toshiba CFD report TICD07-LW2-FNDC0023 Rev 1, the JH Kerr Model test for Contract 0242-984-052, and analysis in this report – Note that operation below 80 ft is not recommended at this time.
 2. Low head operation was based on a similar unit model testing, and thus has uncertainty. Field verification is needed to validate heads less than 80 ft.
 3. Assumes a 98% efficient generator
 4. Head does not consider head loss in penstock, which will increase with power at a given head. It is estimated that there will be a maximum 1 ft head loss at maximum flow.
 5. Low power operating limits based on rough zone avoidance; it assumes operation at less than 40% wicket gate will be rough. Rough zones should be avoided at all times. The 40% wicket gate should be field verified.
 6. High power operating limits based on a Tailwater of 424. Other tailwaters may require further restrictions, as provided by HDC.



Power Outputs versus Tailwater

| | | Head (Forebay - Tailwater) [ft] | | | | | | | | | | | | | | | | | | |
|--------------------------|-------|---------------------------------|------|------|------|------|------|------|------|------|-------|------|-------|------|-------|------|-------|------|-------|------|
| | | 80 | 82.5 | 85 | 87.5 | 90 | 92.5 | 95 | 97.5 | 100 | 102.5 | 105 | 107.5 | 110 | 112.5 | 115 | 117.5 | 120 | 122.5 | 125 |
| Tailwater Elevation [ft] | 422 | 13.1 | 13.6 | 14.0 | 14.5 | 15.0 | 15.4 | 15.8 | 16.2 | 16.5 | 17.2 | 17.7 | 18.2 | 18.6 | 18.7 | 18.8 | 18.9 | 19.0 | 19.1 | 19.2 |
| | 422.5 | 13.4 | 13.9 | 14.4 | 14.9 | 15.4 | 15.9 | 16.2 | 16.6 | 16.9 | 17.6 | 18.1 | 18.6 | 19.2 | 19.4 | 19.6 | 19.8 | 20.0 | 20.2 | 20.4 |
| | 423 | 13.6 | 14.2 | 14.7 | 15.2 | 15.8 | 16.2 | 16.6 | 17.0 | 17.3 | 17.9 | 18.4 | 19.0 | 19.5 | 19.8 | 20.0 | 20.3 | 20.6 | 20.8 | 21.1 |
| | 423.5 | 13.7 | 14.3 | 14.9 | 15.5 | 16.1 | 16.6 | 17.0 | 17.3 | 17.7 | 18.2 | 18.7 | 19.3 | 19.9 | 20.2 | 20.4 | 20.7 | 21.0 | 21.3 | 21.6 |
| | 424 | 13.7 | 14.4 | 15.0 | 15.7 | 16.3 | 16.9 | 17.3 | 17.7 | 18.1 | 18.5 | 19.0 | 19.6 | 20.2 | 20.5 | 20.8 | 21.1 | 21.4 | 21.8 | 22.1 |
| | 424.5 | 13.7 | 14.4 | 15.1 | 15.8 | 16.6 | 17.1 | 17.6 | 18.0 | 18.4 | 18.8 | 19.3 | 19.9 | 20.4 | 20.8 | 21.1 | 21.5 | 21.8 | 22.2 | 22.5 |
| | 425 | 13.7 | 14.5 | 15.3 | 16.0 | 16.8 | 17.4 | 17.9 | 18.3 | 18.8 | 19.1 | 19.6 | 20.2 | 20.7 | 21.1 | 21.5 | 21.9 | 22.3 | 22.6 | 23.0 |
| | 425.5 | 13.8 | 14.6 | 15.4 | 16.2 | 17.0 | 17.6 | 18.1 | 18.5 | 19.0 | 19.4 | 19.9 | 20.5 | 21.0 | 21.4 | 21.7 | 22.1 | 22.5 | 22.8 | 23.2 |
| | 426 | 13.8 | 14.6 | 15.4 | 16.2 | 17.0 | 17.7 | 18.1 | 18.6 | 19.0 | 19.7 | 20.3 | 20.8 | 21.3 | 21.6 | 21.9 | 22.2 | 22.5 | 22.9 | 23.2 |
| | 426.5 | 13.8 | 14.6 | 15.4 | 16.2 | 17.0 | 17.7 | 18.1 | 18.6 | 19.0 | 20.1 | 20.6 | 21.1 | 21.6 | 21.9 | 22.1 | 22.4 | 22.7 | 22.9 | 23.2 |
| | 427 | 13.8 | 14.6 | 15.4 | 16.2 | 17.0 | 17.7 | 18.1 | 18.6 | 19.0 | 20.4 | 20.9 | 21.4 | 21.9 | 22.1 | 22.4 | 22.6 | 22.8 | 23.0 | 23.2 |
| | 427.5 | 13.8 | 14.6 | 15.4 | 16.2 | 17.0 | 17.7 | 18.1 | 18.6 | 19.0 | 20.8 | 21.3 | 21.8 | 22.3 | 22.5 | 22.6 | 22.8 | 22.9 | 23.1 | 23.2 |
| | 428 | 13.8 | 14.6 | 15.4 | 16.2 | 17.0 | 17.7 | 18.1 | 18.6 | 19.0 | 21.1 | 21.7 | 22.2 | 22.7 | 22.8 | 22.9 | 23.0 | 23.1 | 23.2 | 23.3 |
| | 428.5 | 13.8 | 14.6 | 15.4 | 16.2 | 17.0 | 17.7 | 18.1 | 18.6 | 19.0 | 21.1 | 21.8 | 22.5 | 23.2 | 23.2 | 23.2 | 23.2 | 23.3 | 23.3 | 23.3 |
| | 429 | 13.8 | 14.6 | 15.4 | 16.2 | 17.0 | 17.7 | 18.1 | 18.6 | 19.0 | 21.1 | 21.9 | 22.6 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| | 429.5 | 13.8 | 14.6 | 15.4 | 16.2 | 17.0 | 17.7 | 18.1 | 18.6 | 19.0 | 21.1 | 21.9 | 22.6 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| 430 | 13.8 | 14.6 | 15.4 | 16.2 | 17.0 | 17.7 | 18.1 | 18.6 | 19.0 | 21.1 | 21.9 | 22.6 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | |

Notes:

1. Operational limits are in MW.
2. Based off the Toshiba CFD report TICD07-LW2-FNDC0023 Rev 1
3. Assumes a 98% efficient generator
4. Head does not consider head loss in penstock, which will increase with power at a given head. It is estimated that there will be a maximum 1 ft head loss at maximum flow.
5. Values should be validated at various head levels to ensure CFD report is valid.



Functional Description
Document Data
(Cover Sheet)

TITLE: Turbine Noise Investigation Report

UNIT: Unit 1

PURPOSE: For Review

USACOE CONTRACT: W9126G-07-C-0023

SPECIFICATION FOR: Section 15990 Para 3.12.3

TIC DOCUMENT NO.: TICD07-LW2-FNDC-335

TSB DOCUMENT NO.:

NUMBER OF PAGES: 35

| Rev | Date | Description |
|-----|------------|-------------|
| 0 | 03-21-2014 | Initial |

Notes:

Includes for Reference:

Repair Procedure - EKQ003507

Review for the turbine noise issue indicated in the commissioning test- ECS K2013G0088-a

PROJECT:
Lake Whitney
Turbine Generator Rebuild/ Overhaul

TIC PROJECT:
TICD07-LW2

Lake Whitney

Unit 1 Turbine Noise Investigation

Date of testing – March 11, 2014

1. Purpose

During the commissioning of Unit 1 at Lake Whitney in March 2013, a distinct high pitch sound was observed in the turbine area. It occurred when the wicket gates were open between 62% and 75%. It disappeared with the gate opening deviating from that range. Spectral analysis of sound recordings carried out at that time revealed that the frequency of the sound was approx. 355 Hz. Based on preliminary investigations, the commissioning team suggested that the source of the sound is vibration of runner blades, in response to Karman vortices, shedding from the blades.

2. Runner Modifications

As a follow-up of the initial testing, Toshiba carried out an analysis of possible sources of the phenomenon (refer to ECS K2013G0088-a). The studies confirmed that Karman vortices could be produced in the lowest part of the blade, where flow is perpendicular to the blade trailing edge. A bevel cut of the trailing edge made with the purpose of avoiding formation of these vortices, was deemed insufficient. Consequently, a correction procedure was proposed (refer to EKQ003507-a).

Trailing edges of both runners, for Unit 1 and Unit 2, were modified on site according to the Toshiba procedure.

3. Verification of Turbine Noise

During re-commissioning of the turbine on March 11, 2014, a test was carried out to verify if the correction of the blade trailing edge brought desired results.

Test conditions are shown in Table 1.

Table 1

| Time | Lake Level | Tailwater | Power | Gate |
|-------|------------|-----------|-------|------|
| | ft | ft | MW | % |
| 11:27 | 521.60 | 425.47 | 2.94 | 23.0 |
| 11:31 | 521.60 | 425.85 | 6.83 | 39.6 |
| 11:33 | 521.60 | 426.17 | 10.30 | 50.0 |
| 11:37 | 521.60 | 426.54 | 13.07 | 60.0 |
| 11:40 | 521.60 | 426.84 | 14.43 | 65.0 |
| 11:43 | 521.60 | 427.06 | 15.88 | 70.0 |
| 11:45 | 521.60 | 427.21 | 17.11 | 75.0 |
| 11:47 | 521.60 | 427.26 | 18.10 | 79.0 |
| 11:51 | 521.60 | 427.31 | 18.51 | 80.0 |
| 11:53 | 521.60 | 427.36 | 18.56 | 81.0 |
| 11:55 | 521.60 | 427.40 | 18.66 | 82.0 |

The noise recording was carried out by the draft tube mandoor in all measured points. During the entire test there was no sound of vibrating blades. Spectral analysis of the recorded sound confirmed this finding. Figures 1 and 2 compare 2013 recordings at 70% and 75% gate openings with 2014 measurements for the same gate positions.

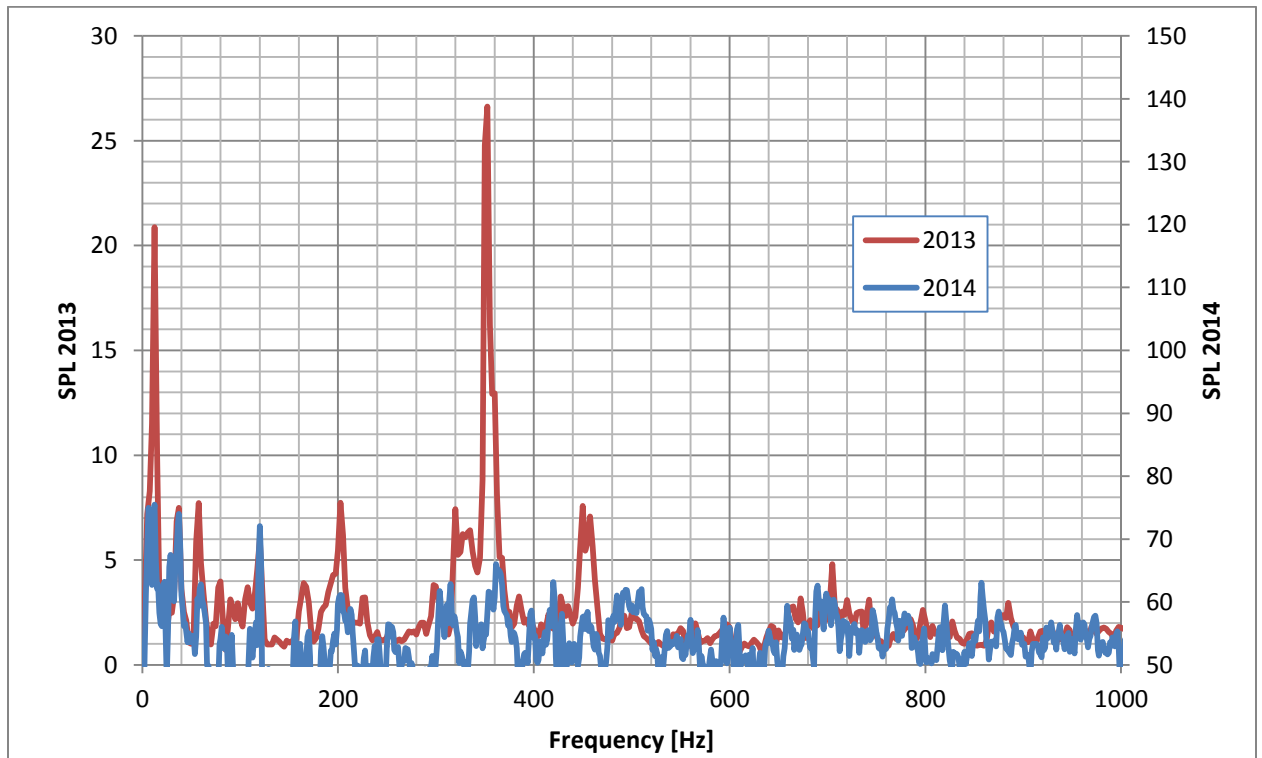


Figure 1 Turbine noise spectrum at 70% gate

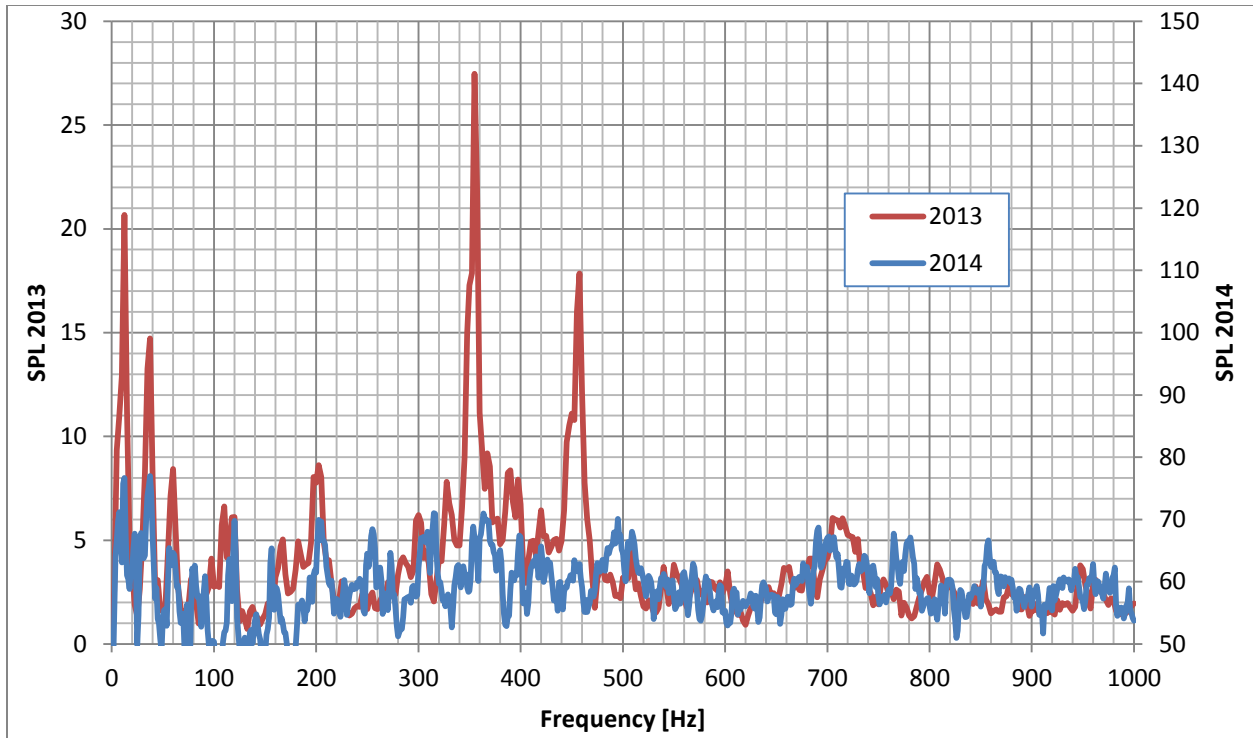


Figure 2 Turbine noise spectrum at 75% gate

Even the two compared noise recordings were carried out with the same Bruel&Kjaer instrument, different instrument settings were used in both cases. For this reason the noise spectrum (SPL = Sound Pressure Level) for the compared cases was shown on two different axes. For the purpose of comparison, the graph scales were selected so the compared spectra were approximately the same at 1000 Hz. At this frequency filtration for dBA scale has the value of “0” (it is not certain if dBA scale was used in 2013 recording).

Figures 1 and 2 confirm the complete absence of the sound of Karman vortex-induced blade vibration.

4. Conclusion

Modification of the blade trailing edges of the runner confirmed that the diagnosis of the source of the phenomenon was correct. Blade vibration is no longer observed in operation of Unit 1. Unit 2 runner was modified to the same specification and is expected to behave in the same way.

宛先 TO

US Army Corps of Engineers

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| プラント PROJECT Whitney Lake Power Station | 機器名 EQ/SYS. A New Runner for Turbine Generator Rebuild/Overhaul | 製造/見積番号 JOB/QUOT.NO. |

題目 SUBJECT

Review for the turbine noise issue indicated in the commissioning test

Regarding to turbine noise issue indicated in the commissioning test, we, Toshiba, reviewed and studied it. Then following results were given,

1. Assessment for the overall commissioning test results

Following points were concluded.

- Measured/converted turbine output at 100 ft of net head was 21.3 MW against 19.39 MW(26,000 hp) of the guaranteed one.
- Shaft vibration was very good, vibration decreased with load and temperature, 1X filtered was less than 1 mil at full load.
- No abnormal vibration/noise were detected excepting a pronounce high pitch sound from the turbine at 64% gate opening and 15 MW.
- Spectrum analysis of above mentioned noise is shown in Figure 1.

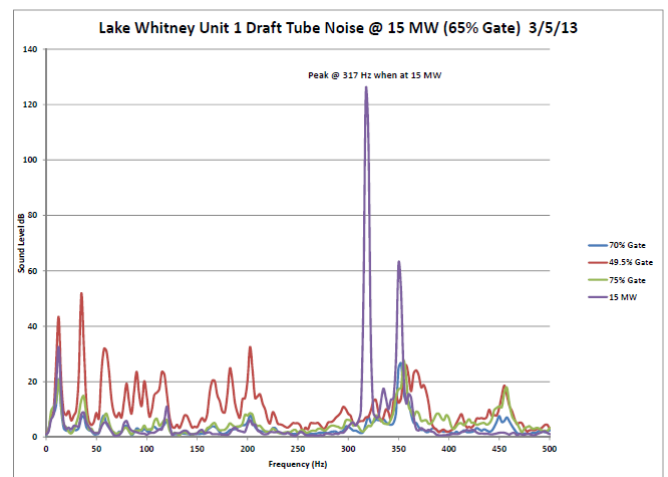


Figure 1. Spectrum of the draft tube noise

| | | | |
|-----------------------|--|---|-----------------------------------|
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| | | Hydraulic Turbine Dept. Hydraulic Turbine Design Group | T. Kurokawa 8, April, 2013 |
| | | | 担当 PREPARED BY |
| | | | Kaneo SUGISHITA 8, April, 2013 |

2. FTA result about the noise

FTA (Fault Tree Analysis) about the noise was carried out. And its result is shown in Appendix A. Its summary is as follows,

- Anti-Karman vortex chamfer was equipped at all runner blades of the Whitney Lake runner.
- However according to the frequency of the noise and the tendency of the noise changing with the gate opening, it can be seen that Karman vortex from the runner blades trailing edge near to the band conjunction are most doubtful cause of the noise.

3. Possible countermeasure of the noise

Based on the conclusion of the FTA, modification of the runner trailing edge as shown in Figure 2 is proposed to reduce the noise.

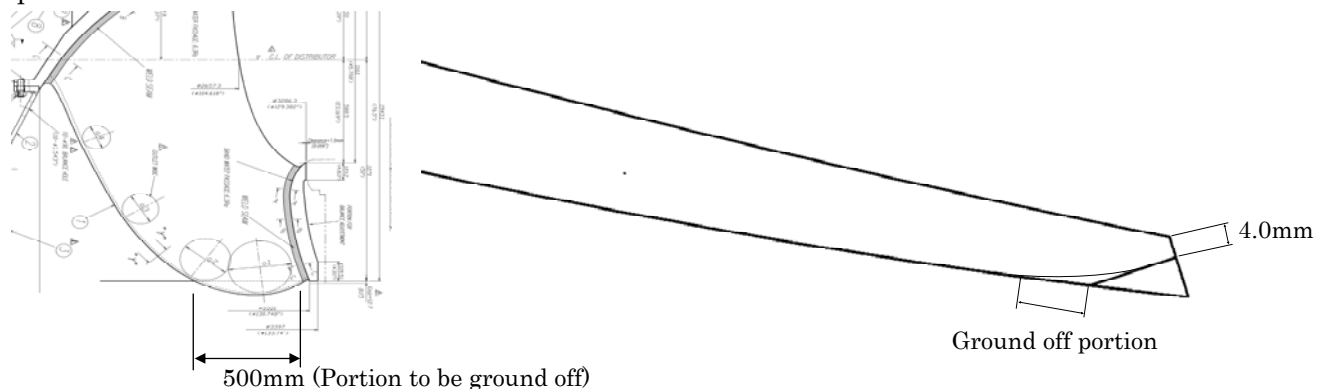


Figure 2. Modification of the runner trailing edge

(Note)

- Above mentioned modification will be carried out by grinding.
- The grinding shall be carried out by a skilful specialist
- The modification work can be carried out in situ condition.

4. Some additional discussion about the noise issue

Other countermeasure to reduce the noise level

If the noise is caused by the Karman vortex generated at the runner blade trailing edge near to the band conjunction, it can be expected that pressure fluctuations caused by the Karman vortex can be reduced or relaxed by the admitted air. According to the commissioning test result, head cover presser seemed to be lower than the atmospheric pressure, so the air can be sucked through the head cover air admission pipe if its control valve is opened. Those sucked air go through the runner cone and may hit the runner trailing edge or pass nearby. Then above mentioned effect can be expected.

Assessment for the mechanical damage of the Karman vortex

Mechanical strength of the Whitney Lake runner was assessed in Appendix B. According to the expected worst stress condition indicated by the FEM analysis for the similar Francis turbine, maximum mean stress generated at the runner blade will be 282 MPa (including the possible

maximum residual stress generated during the manufacturing process of 150 MPa). Also according to the strict quality control criteria applied for the Whitney Lake runner (Class 1 of CCH70-3), maximum defect size left in the runner metal will be less than 2mm. So based on those conditions, it can be said that the dynamic stress less than +/- 30.7 MPa can not enlarge the defects left in the runner. This means that the runner will be safe under the dynamic stress of +/- 30.7 MPa.

According to above mentioned points, followings can be said,

The maximum mean stress of the runner blade due to the centrifugal force and the pressure distribution upon the blade surface is 132 Mpa. So it is very unusual that the dynamic stress of 30.7 Mpa occurs under the normal operating condition. If such unusual dynamic stress occurs, some abnormal phenomena, such as large vibration or pressure fluctuation, other than the noise, must be observed.

However according to site test result, it was confirmed that the draft tube pressure time waveform changed from random to a periodic 1 Hz sine wave between 53 to 68% gate position but sound was not really evident until 65% gate and there was no change in shaft or bearing housing vibration when draft tube noise was heard.

Therefore it can be said that large dynamic stress such as +/- 30,7 MPa will not occur.

Appendix A. FTA result about the noise

FTA chart is shown below. Precise discussions are to be referred to each Note.

| | Component | Mechanism | Discussion | Evaluation |
|---|--|--|--|------------|
| <div style="border: 1px solid black; padding: 5px; width: fit-content;"> Pronounce high pitch sound from the turbine Range: 62-67% gate Frequency: 317Hz </div> | Wicket gate vane | Karman vortex for the trailing edge | Frequency is different. (Note1) | × |
| | Runner blade | Karman vortex for the trailing edge of anti-Karman vortex chamfer (Correctly manufactured) | Frequency is different. (Note2) | × |
| | | Karman vortex for the trailing edge (other portion) | Frequency is near. (Note2) | △ |
| | | Karman vortex for the thicker trailing edge of anti-Karman vortex chamfer (Incorrectly manufactured) | No incorrect trailing edge (Inspection record) (Note2) | × |
| | Runner cone | Edge tone at pressure releasing holes | Frequency is different. (Note3) | × |
| Cavity of the draft tube manhole | Edge tone at the cavity of the manhole | Same as the existing one | × | |

(Note 1)

Wicket gate vane of the Whitney Lake Francis turbine has a round tailing edge, which diameter is 15.875mm (=5/16 inch R). So its Karman vortex frequency is calculated as shown in Figure A1. According to this figure, it can be seen that the estimated Karman vortex frequency of the wicket gate vane is different from the observed one. Furthermore its frequency dose not change according to the wicket gate opening. This is different tendency from the observed one. Therefore it can be said that the Karman vortex of the wicket gate vane dose not cause the observed noise.

(Note 2)

As for the runner tailing edge of the Whitney Lake runner, anti-Karman vortex chamfer as shown in Figure A2 is equipped. Usually this kind of chamfer prevents Karman vortex formation. However if the Karman vortex is supposed to be generated from the outlet edge corresponding to t/3 portion of Figure A2, its frequency is calculated as shown in Figure A3. According to this figure, it can be seen that the estimated Karman vortex frequency for the runner blade is different from the observed one. If the Karman vortex from the runner generates the noise observed in the site, its thickness must be around 8 mm.

If the trailing edge is not manufactured properly and its actual thickness is equal to 8 mm, Karman vortex may occur from the outlet edge of the runner blade. However according the internal inspection records for the Whitney Lake runners, it was confirmed that the outlet edges were properly manufactured.

So another hypothesis for Karman vortex generation is, the Karman vortex is generated from the upstream portion from the outlet edge, where thickness is larger than $t/3$ and is equal to 8 mm. This hypothesis is confirmed by the experimental result as shown in Figure A4 (referred to the paper⁽¹⁾). According to this experimental result, it can be seen that the trailing edge with stepper chamfer, such as the profile number 2 as shown in Figure A4, might generate Karman vortex vibration. So to reduce the vibration, the trailing edge such as profile number 2 shall be modified as the profile number 3, 4 or 5.

The reason why the Karman vortex occurs in the Whitney Lake runner is as follows,

- At the trailing edge near to the band conjunction, flow crosses right angle (=90 deg.) against the trailing edge.
- At the trailing edge for other portion than the above, flow crossed shallow angle (<90 deg.) against the trailing edge. So effective angle of the trailing edge is smaller than the actual geometrical angle (less than 30 deg.).
- As a result, the Karman vortex occurs only from the tailing edge near to the band conjunction.

Therefore modification for the Whitney Lake runner shall be carried out only for the one near to the band conjunction.

(Note 3)

It is know that vibration occurs due to edge tone phenomenon when flow crosses the cavity. As for hydraulic turbine, vibration occurs when flow passes across a hole, as shown in Figure A5. In this case the frequency of the vibration f is related to the velocity V and the diameter of the hole d_B as below,

$$f = 0.5 \times V / d_B$$

In case of the runner cone of the Whitney Lake runner, there were some holes to release pressure as follows,

| | Size of hole (d_B) | Number of holes | Location (D_L) |
|---------------------|------------------------|-----------------|--------------------|
| Conical portion | $\phi 90$ | 10 | $\phi 691.5$ |
| Cylindrical portion | $\phi 120$ | 6 | $\phi 508$ |

Expected frequencies of above mentioned hole are calculated as shown in Figure A6. According to this figure, it can be seen that the estimated vibration frequencies is different from the observed one. Therefore it can be said that the vibration generated at the holes of the runner cone dose not cause the observed noise.

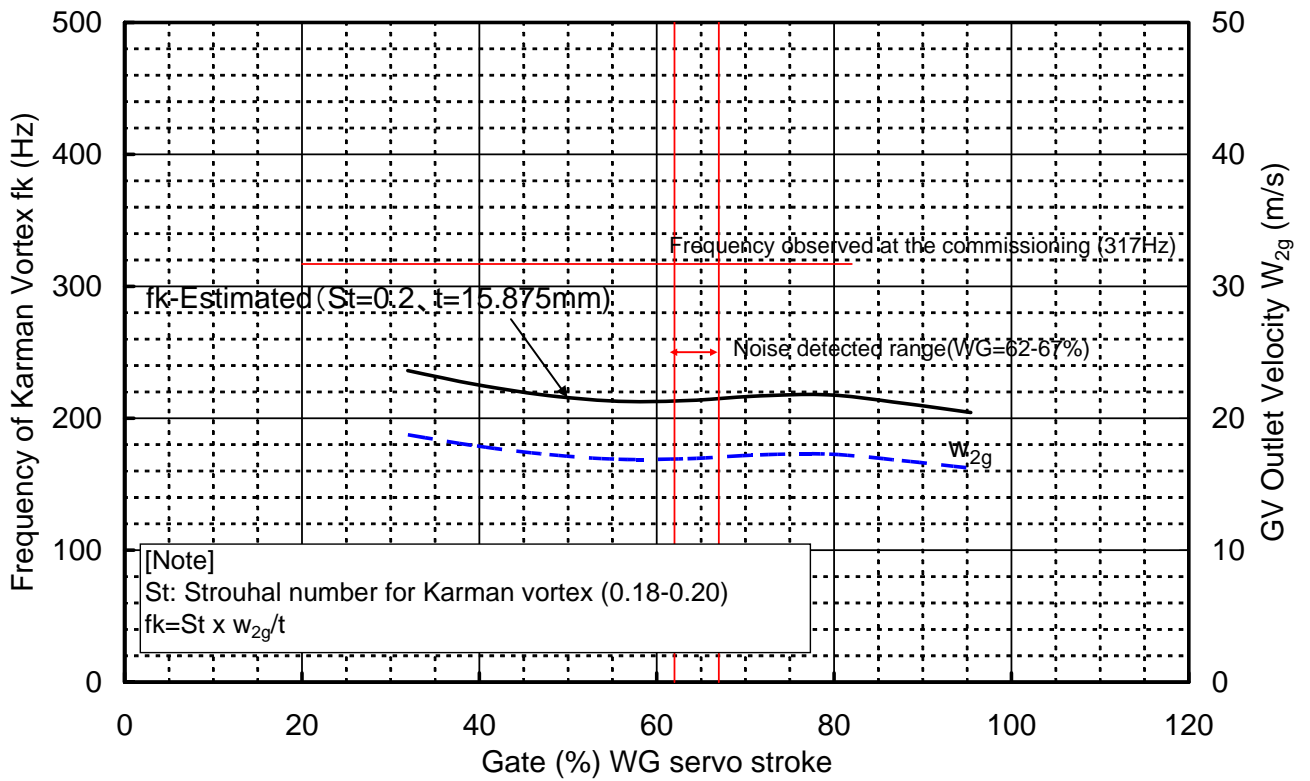
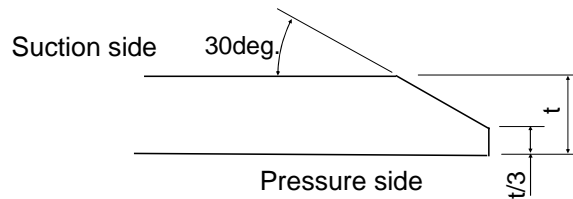


Figure A1. Estimated frequency of the Karman vortex from the wicket gate vane

[Remark]

$$\text{Velocity } W_{g2}(\text{m/s}) = \text{Flow } Q(\text{m}^3/\text{s}) / \text{Wicket gate flow passage height} / \text{Wicket gate opening}$$

Flow Q was estimated according to the commissioning test result (Wicket gate opening vs. output)



(Whitney Lake runner; $t/3 = 4.0\text{mm}$ near to the band conjunction)

Figure A2. Anti-Karman vortex chamfer for runner blade

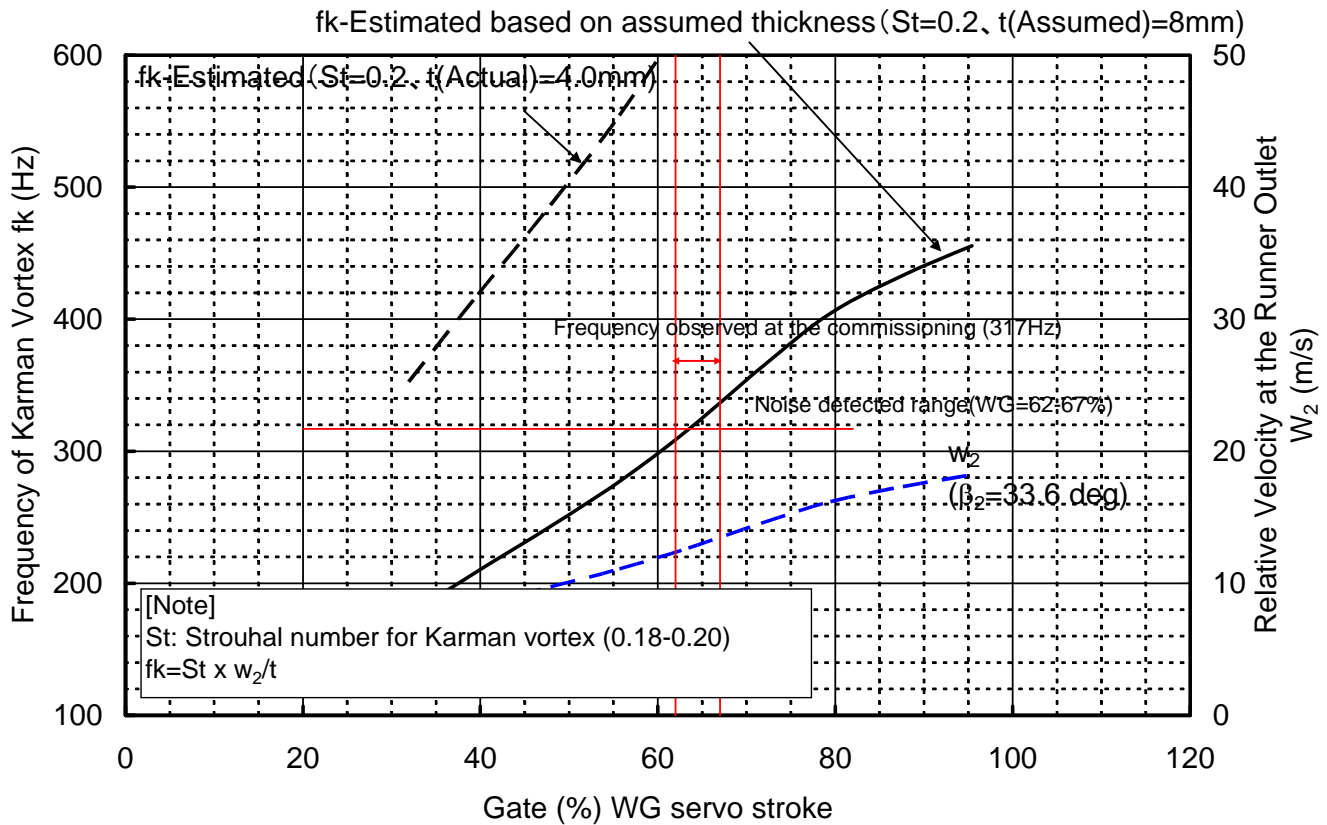


Figure A3. Estimated frequency of the Karman vortex from the runner blade

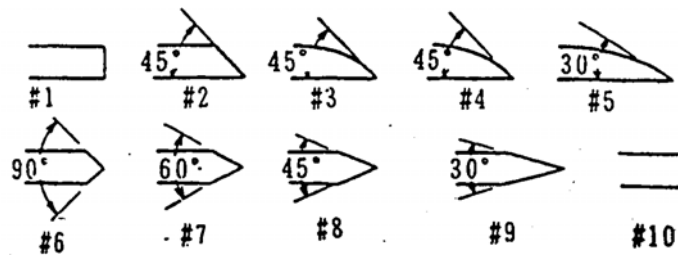
[Remark]

Velocity W_2 (m/s)=Flow Q(m³/s)/Outlet section of the runner Ae/sin(β_2)

Flow Q was estimated according to the commissioning test result (Wicket gate opening vs. output)

$A_e = \pi D_e^2 / 4$ (D_e : runner outlet diameter 3321mm)

β_2 : Runner blade outlet angle=33.6 deg. (Supposed value for the band conjunction portion)



| Profile No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|------------------------|-----|----|---|---|---|-----|-----|----|---|----|
| Amplitude of vibration | 100 | 38 | 3 | 0 | 0 | 190 | 380 | 43 | 0 | 31 |

Figure A4. Relation between trailing edge profiles and the effects of countermeasure of resonance ⁽¹⁾

(1) Heskestad ,G. et al. "Influence of trailing-edge geometry on hydraulic-turbine-blade vibration resulting from vortex excitation", Journal of Engineering for Power, April 1960

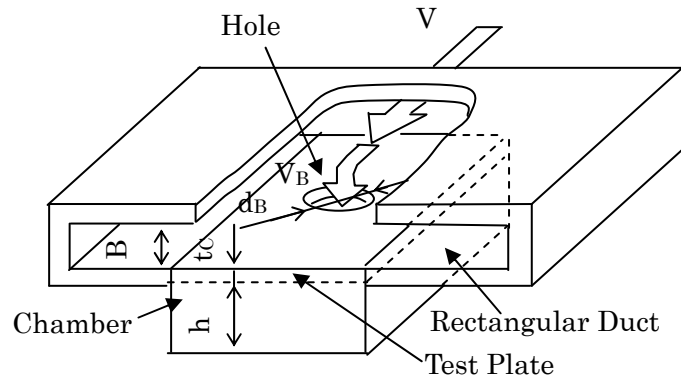


Figure A5. Edge tone vibration occurring at a hole

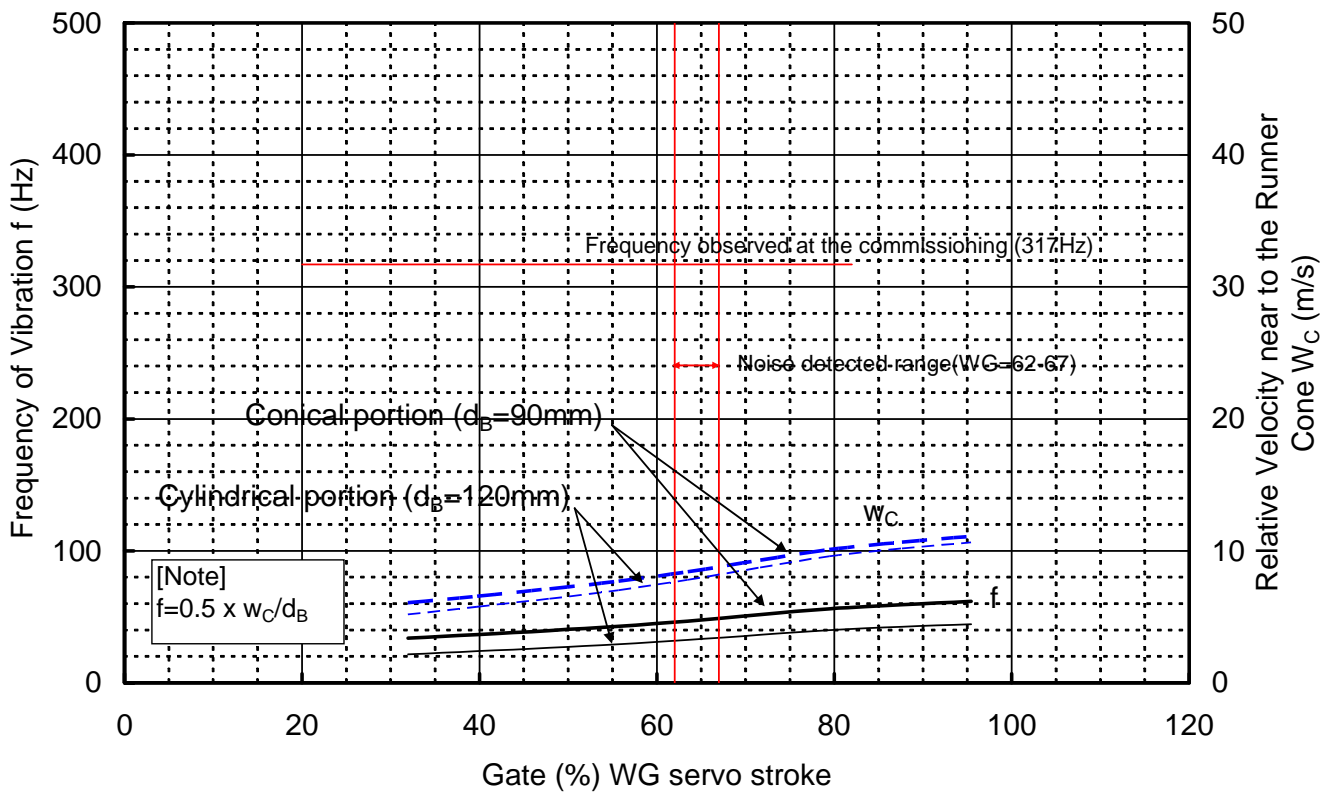


Figure A6. Estimated frequency of the vibration generated at the runner cone holes

[Remark]

$W_m = \text{Flow } Q(\text{m}^3/\text{s}) / \text{Outlet section of the runner } A_e$

$W_r = \pi D_h n / 60$ (n : Rotating speed of the runner 128.6 min^{-1})

Velocity around the hole of the runner cone

$$W_C(\text{m/s}) = \sqrt{W_m^2 + W_r^2}$$

Appendix B. Assessment for the mechanical strength of Whitney Lake runner

As for the 13Cr-4Ni cast stainless steel, such as ASTM A743 CA6NM, used for the Whitney Lake runner, many studies have been carried out. According to our study results ⁽²⁾, the growth rate of crack, (da/dn), plotted against ΔK for 13Cr-4Ni cast stainless steel in water was given as shown in Figure B1. From this figure, the threshold value of ΔK against the stress ration R was given as shown in Figure B2. Then the allowable defect size for any combination of the mean stress and the dynamic stress can be calculated upon the modified Goodman's diagram as shown in Figure B3.

Combination of the mean stress and the dynamic stress for the Whitney Lake runner was estimated as below,

Maximum mean stress= 132 MPa

(Note) Above value is corresponding to the maximum mean stress occurring at the outlet of runner blade at the crown conjunction, given by the FEM analysis for the similar Francis turbine, which head was 158 ft. (Stress of a runner mainly depends on head and does not depend its size, so above mentioned value seems to be severer than the Whitney Lake runner.)

Residual stress generated during the manufacturing process= 150 MPa (=Possible maximum)

So, total mean stress =132+150=282 MPa (=Possible maximum)

Furthermore the quality control level of the Whitney Lake runner was Class 1 according to CCH70-3 so maximum permissible defect was sharp defect with 2mm length. The defect with 2mm length is corresponding to $2a=2/2=1\text{mm}$, so it can be said that the Whitney Lake runner can withstand the dynamic stress less than +/- 30.7 MPa.

(2) Tanaka, H. et al. "Study on dynamic stress of runners for the design of 760 meter head pump-turbines", 16th Symposium of the IAHR September 1992

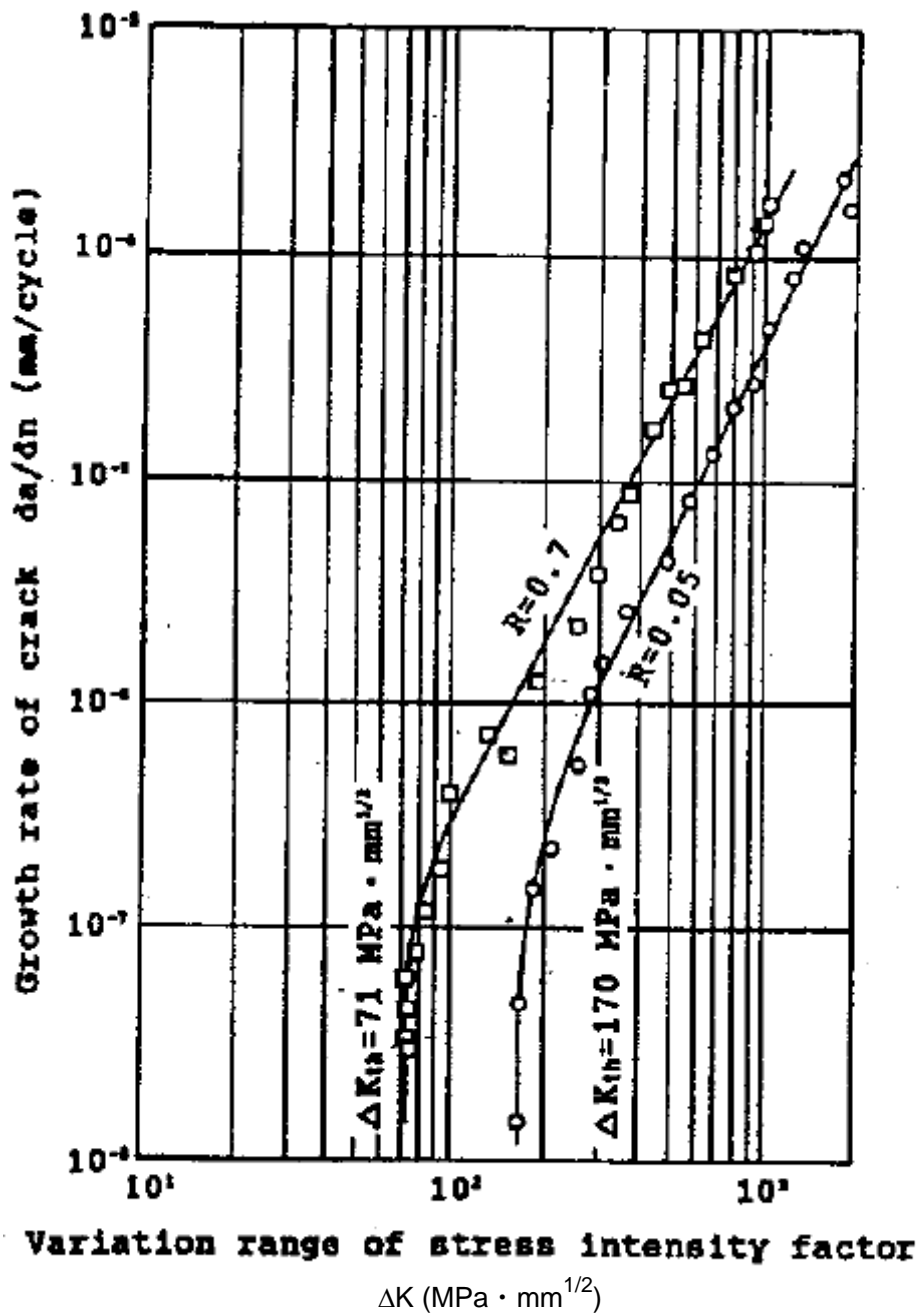


Figure B1. Growth rate of crack (da/dn) and variation range of stress intensity factor (ΔK) for 13Cr-4Ni stainless steel in water (Toshiba's internal experimental results) ⁽²⁾

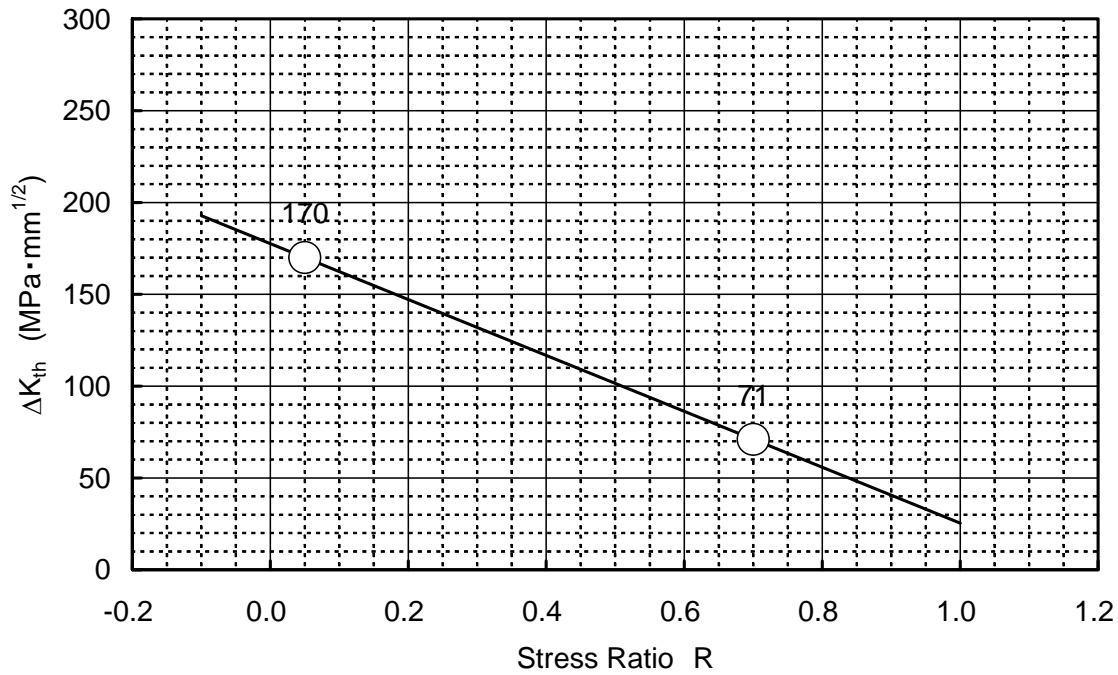


Figure B2. Threshold stress intensity factor (ΔK) and stress ratio for 13Cr-4Ni stainless steel in water (Toshiba's internal experimental results)

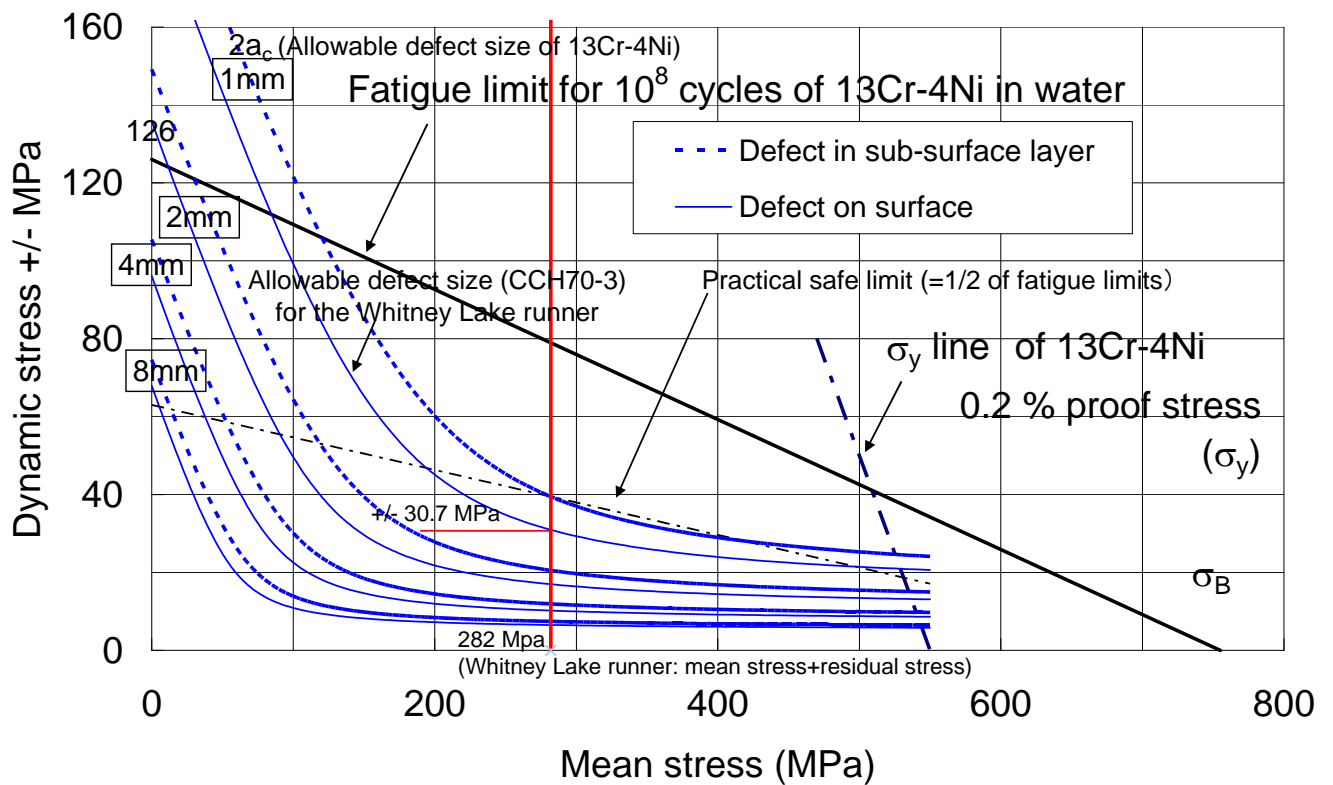


Figure B3. Allowable size of defects for 13Cr-4Ni stainless steel

US ARMY CORPS of ENGINEERS

**A New Runner for Turbine Generator
Rebuild/Overhaul
at WHITNEY LAKE Powerhouse**

**Procedure for the Runner Trailing Edge
Modification**

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Toshiba Corporation

TOSHIBA CORPORATION

説明書 Explanation

名称 TITLE

Procedure for the Runner Trailing Edge Modification

客先名 CUSTOMER : US ARMY CORPS of ENGINEERS
 系統機器 EQ/SYS. :
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Contents

| | Page |
|---|------|
| 1. Preface | 4 |
| 2. Modification to be carried out | 4 |
| 3. Procedure for the modification | 5 |
| 3.1 Preparation for the modification | 5 |
| 3.2 Grinding | 5 |
| 3.3 Inspection after the grinding | 6 |
| 4. Back to the operation | 6 |
| | |
| Appendix | 7-19 |

1. Preface

This document shows procedure of modification work to be done at the runner trailing edge to reduce the noise reported in the report of ECS K2013G0088.

2. Modification to be carried out

Range of the trailing edge to be modified is approximately 500mm range from the band conjunction as illustrated below. Figure 1 shows the modification to be carried out at the representative sections of the runner trailing edge. Table 1 and Figure 2 show the location of each section.

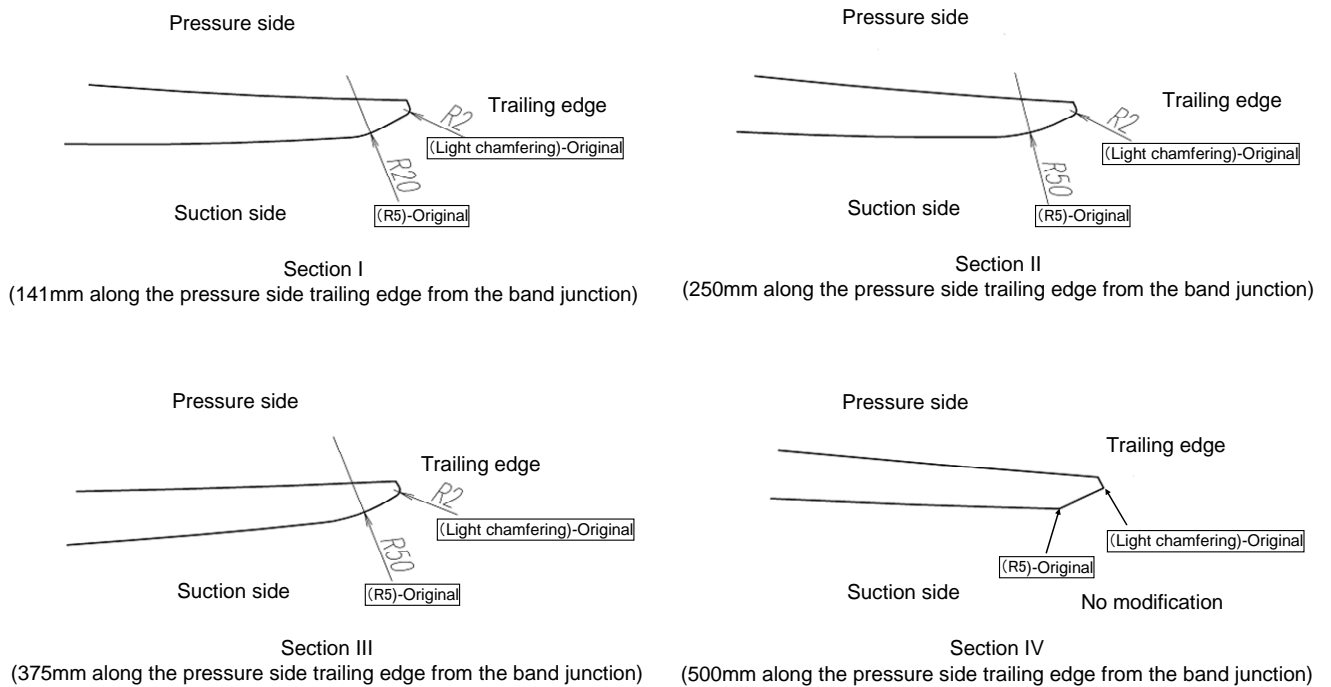


Figure 1. Representative sectional shapes

Table 1. Locations of the representative section

| Section No. | R (mm) | L (mm) |
|-------------|--------|--------|
| I | 1539.8 | 141 |
| II | 1438.2 | 250 |
| III | 1316.6 | 375 |
| IV | 1199.2 | 500 |

(Note) Position indicated above values is corresponding to the point on the pressure side trailing edge.

The range of the trailing edge to be modified is from the end of rout of the band conjunction to the Section IV. (L<500mm)

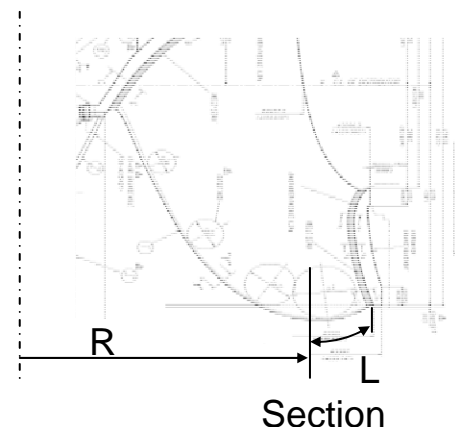


Figure 2. Locations of the representative sections

3. Procedure for the modification

Above mentioned modification shall be carried out according to following procedure.

3.1 Preparation for the modification

Before the modification is started, following preparation shall be carried out.

(In case of the runner disassembled)

If the Unit is disassembled for runner modification, runner shall be placed vertically on a flat floor. The runner band is placed higher from the floor so that there adequate clearance between the runner blade and the floor to allow the modification work to be done easily.

Furthermore proper containment for dust/particles generated in the grinding process (refer to 3.2) and chemical liquid contamination due to the passivation process (refer to 3.3.3) shall be taken into account.

3.2 Grinding

[Caution Note]

To avoid cross contamination of Materials the following precautions must be taken.

A containment must be set up with ventilation around the runner to avoid dust contamination in the power house and the runner.

When removing material from runner do not use any grinding abrasives that where used previously on other metals. Use only new metal removing abrasives s for stainless steal only.

The modification of the trailing edge shall be carried out by grinding according to the following procedure.

- (1) Locations of the representative sections (Section I, II, III and IV) shall be marked based on the description of the locations shown in Table 1 and Figure 2.
- (2) Section I, II and III shall be reshaped by grinding using specified templates. The reshaping shall be carried out so that an edge of the template shall contact the blade surface equally.
- (3) Pictures of the used templates are shown in Section A1 of Appendix. Each template was precisely manufactured based on the three dimensional coordinate data of the runner blade surface, so called "CATIA data". Each template was compared with the intended blade shape based on the "CATA data" as shown in Section A2 of Appendix and it was confirmed that each template had been manufactured correctly according to the design shape.

(Note) Material of the template

Material: SPCC-SD (JIS G3141 2011) Corresponding to ISO 3574: 2008

(Cold-reduced carbon steel sheet of commercial and drawing qualities)

Surface finish: Electro-galvanizing

- (4) After the reshaping of three representative sections (Section I, II and III) is finished, portion between the representative sections shall be reshaped by grinding so as to change gradually from the one section to the other section.
 - (5) Section IV indicates the limit of the modification and it is corresponding to the original shape. So the modification from the section III and the section IV shall be done so that the trailing edge is changed gradually from the Section III shape to the original shape (the section IV shape).
-

- (6) The modification work from the section I and the band conjunction shall be done so that modified shape is changed gradually from the Section I shape to the root of the runner blade.
- (7) After the reshaping by grinding, ground surface shall be finished so that its surface roughness shall be less than the specified range. (less than 3.2 Ra)
- (8) After the process mentioned above is finished, the modified surface shall be wiped with a clean, solvent-moistened cloth so that any particle of the grindstone would not left on the blade surface.

Tools and instruments to be used shown in Table 2 shall be prepared for above mentioned work.

Table 2. Tools and instruments

| Name of the tool/instrument | Description | Remark |
|-----------------------------|---|--------|
| Grinder | Hand grinder for grinding and polishing, activated by compress air. | |
| Grind stone | Grind stones for the stainless steal without iron contamination | |
| Compressed air supply | | |
| Lighting | If required | |
| Ventilation instrument | If required | |

3.3 Inspection after the grinding

Following inspections shall be carried out after the grinding.

3.3.1 Inspection for the modified shape

Sectional shapes of the Section I, II and III shall be check by the templates used for grinding.

Maximum gap between the edge of the template and blade surface shall be measured for all runner blades.

Measured results shall be tabled in the table shown in SectionA3 of Appendix.

Criteria: the maximum gap shall be less than 0.5mm.

3.3.2 Inspection for defects

Penetrant examination shall be carried out to confirm that no unacceptable defect is left at the modified area.

Procedure; Refer to PQA-K087X064-B

Measured results shall be reported similar way as shown in SectionA4 of Appendix.

Criteria: Not larger than Class 2 of CCH70-3

Defects more than Class 1 of CCH70-3 shall be recorded.

3.3.3 Passivation

The ground blade surface shall be chemically passivated as required in Section 15990, Paragraph 2.1.4 of the contract specification. So passivation using nitric solution will be carried out. Before and after the passivation, the surface shall be cleaned up according to the required procedure, such as ASTM A 380, Paragraph 6.4.

Regarding to the above mentioned passivation process, a separated document (submitted later) shows precise procedure will be subs

3.3.4 Corrosion examination

Corrosion examination shall be carried out to confirm that the surface free from iron contamination.

Procedure; Refer to PQA-K087X064-B

Measured results shall be reported similar way as shown in SectionA5 of Appendix.

Criteria: No evidence of rust stains or other corrosion products

4. Involved personnel

Personnel involved in above mentioned process and task of each one will be informed later.

Appendix

- A1. Pictures of the used templates
 - A2. Drawings for the blade shape
 - A3. Table for the record of template gaps
 - A4. Results of the penetrant examination
 - A5. Results of the corrosion test
-

A1. Pictures of the used templates



Figure A1.1 Template for section I



Figure A1.2 Template for section II



Figure A1.3 Template for section III



Figure A1.4 Template for section IV

A2. Drawings for the blade shape

| Section | Drawing No. |
|--------------|-------------|
| Section I: | 4KQ002169 |
| Section II; | 4KQ002170 |
| Section III; | 4KQ002171 |
| Section IV; | 4KQ002172 |

| | | | | | |
|--|--------------------------------------|--|-------------------------------|---|-----------|
| C/H F1 | 図面番号 DRAWING NO. 4KQ002169 | 変更履歴 REVOTG * A B | 名称 TITLE (ABBR) テクニカルマンシギ1 | 普通許容差ハ下記ニヨル 全周削リ KDA3521 溶接品・ガス切断 KDA3524 | M.F. 1 |
| MODEL CODE S.T.A. | | 品質管理 REMARKS 1 GA4 | | コノ図面子指定スル規格・標準値ナシ。 発行年・変更記号ノ指示ガナイモノハ 最新版ヲ適用スルコト | |
| | | | | | |
| (Section I) バンド側カルマン削ぎ開始部 羽根出口端オモテ面に沿って141mm | | | | | |
| 承認 APPROVED BY 調査 REVISIONS | | 承認 APPROVED BY 調査 REVISIONS | | 名称 TITLE 出口端カルマン削ぎ1 | |
| 調査 REVIEWED BY 担当 PREPARED BY 氏名 NAME 記号 CONTENTS | | 調査 REVIEWED BY 担当 PREPARED BY 氏名 NAME 記号 CONTENTS | | 図面番号 DRAWING NO. 4KQ002169 | |
| 類似・参考図 | | TOSHIBA 株式会社 東芝 TOSHIBA CORPORATION | | 電子承認システム適用 電子承認システム適用 | |

A3. Table for the record of template gaps

| Blade No. | Maximum gap between the template and the blade surface | | |
|-----------|--|------------|------------|
| | Section I | Section II | Section IV |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |

Criteria; Maximum measured gap shall be equal or less than 0.5 mm.

A4. Results of the penetrant examination

A sample of the penetrant examination results is attached in the next page.

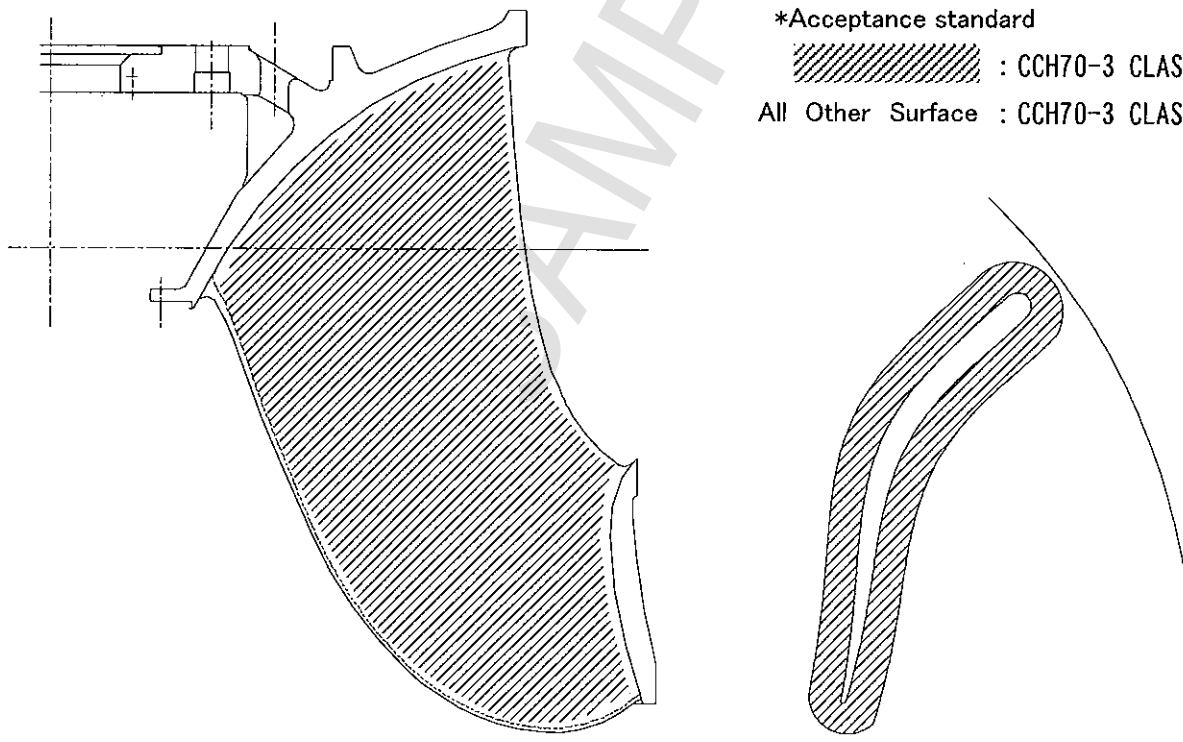
浸透探傷試験成績書
PENETRANT EXAMINATION RECORD

| | | | |
|--------------------------------|------------------------------|---------------------------|----------------------------|
| 注文主 Customer | U.S. Army Corps of Engineers | 施設名 Plant | Lake Whitney Powerhouse |
| 機器名 Item | FRANCIS TURBINE UNIT No. 1 | 部品名 Part | RUNNER |
| 製造番号 Job No. | M228130 CRV 1104 | 数量 Quantity | 1 Unit |
| 図面番号 Drawing No. | 1KQ005933 Rev. E | 材質 Material | CA-6NM (ASTM A743) |
| 適用規格/要領書 Standard/Procedure | PQA-K087X064-B | 試験時期 Examination stage | Final Machining & Grinding |
| | | 試験日付 Examined date | Oct. 3 ~ Oct. 5, 2009 |

| | | | | |
|--------------------------------|------------------|---------------------|---------------------------|--------------------------------|
| 探傷条件 Examined Conditions | 探傷剤 Materials | | 表面状態 Surface condition | Grinding and Machining Surface |
| | 型式名 Brand | 製造者 Manufacturer | 試験方法 Method | Removal water method |
| | 浸透剤 Penetrate | R-3B | 浸透時間 Penetration time | 30 min. |
| | 洗淨剤 Remover | WATER | 探傷温度 Temperature | 21 °C |
| | 現像剤 Developer | R-1S | 現像時間 Developing time | 15 min. |

探傷範囲
Examined area

判定 合格 Acceptable
Evaluation 不合格 Unacceptable



| Part Inspected | Percentage |
|----------------|------------|
| All Surfaces | 100% |

発行課 Q. A. DEPARTMENT 立会者 _____ 試験
 Issued by Q. C. Group1 Witnessed by Examined by T. Nojima

承認 *A. Sakuma* 調査 *S. Kubo* 担当 *T. Nojima*
 Approved by *Oct. 21, 2009* Reviewed by *Oct. 20, 2009* Prepared by *Oct. 20, 2009*

A5. Results of the corrosion test

A sample of the corrosion test results is attached in the next page.

8. Corrosion examination

| | |
|--------------------------|---|
| Examination stage | : Before heat treatment & After heat treatment |
| Part Inspected | : All Surfaces |
| Corrosive Liquid | : Water |
| Duration Time | : 24 Hour |
| Result | : Acceptable |



Before heat treatment



After heat treatment

| 変更 REV. | PAGE | 変更箇所及び内容 CHANGED PLACE AND CONTENT | 承認 APPROVED | 調査 REVIEWED | 担当 PREPARED |
|------------|------|---------------------------------------|-----------------------|-----------------------|-----------------------|
| a | | 初 版 | Written in page 2. | Written in page 2. | Written in page 2. |
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