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Final Report: Retrofit Aeration System (RAS) for Francis Turbine

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TABLE OF CONTENTS

I. INTRODUCTION	1
II. TURBINE EVALUATION STUDY DESIGN AND METHODOLOGY	4
II.A. 2005 Turbine Evaluation	4
II.A.1. Plant Operations	5
II.A.2. Turbine Barrel and Draft Tube Vent Airflow Sampling	5
II.A.3. Discrete Sampling	5
II.A.4. Continuous Monitoring	7
II.B. Quality Assurance	7
III. RESULTS AND DISCUSSION	8
III.A. Water Temperature	8
III.A.1. Water Temperature - 2005	8
III.A.2. Water Temperature Comparison of Study Years	8
III.B. Airflow	9
III.B.1. Main Generator 6 Airflow - 2005	9
III.B.2. Main Generator 6 Airflow - Comparison of Study Years	10
III.B.3. Main Generator 3 Airflow - 2005	11
III.B.4. Main Generator 3 Airflow - Comparison of Study Years	11
III.B.5. Main Generators 3 and 6 Airflow Comparison - 2005	11
III.C. Dissolved Oxygen	12
III.C.1. Main Generator 6 Dissolved Oxygen - 2005	12
III.C.2. Main Generator 6 Dissolved Oxygen - Comparison of Study Years	15
III.C.3. Main Generator 3 Dissolved Oxygen - 2005	16
III.C.4. Main Generator 3 Dissolved Oxygen - Comparison of Study Years	16
III.C.5. Main Generator 3 and 6 Dissolved Oxygen Comparison - 2005	17
III.D. Aeration Performance	18
III.D.1. Aeration Performance - 2005	18
III.D.2. Aeration Performance - Comparison of Study Years	19
III.E. Total Dissolved Gas	20
III.E.1. Total Dissolved Gas - 2005	20
III.E.2. Total Dissolved Gas – Comparison to Study Years	22
IV. CONCLUSIONS	23
IV.A. General Findings	23
IV.B. Main Generator 6	23
IV.C. Main Generator 3	25
IV.D. Comparison of Main Generators 3 and 6	26

LIST OF APPENDICES

Appendix 1 – Report Figures and Table

Appendix 2 – Field and Calculated Data Tables

APPENDIX 1

LIST OF FIGURES

- Figure 1: Modifications made to Main Generator 6 - 2003 and 2005
- Figure 2: Diagram of Discrete Sampling Device
- Figure 3: Photograph of Discrete Sampling Device
- Figure 4: Photograph of Discrete Sampling Device – Deployed
- Figure 5: Relationship between Standard Air Flow and Discharge – Main Generator 6 – Four New Main Vents Only – 7/26/05 & 7/27/05
- Figure 6: Relationship between Air Flow and Discharge – Main Generator 6 – Draft Tube Vent Only – 7/26/05 & 7/27/05
- Figure 7: Relationship between Air Flow and Discharge – Main Generator 6 – Draft Tube and Four New Main Vents – 7/26/05 & 7/27/05
- Figure 8: Relationship between Standard Air Flow and Discharge – Tailrace Elevations 553 – 2005 Main Generator 6
- Figure 9: Relationship between Standard Air Flow and Discharge – Tailrace Elevation 556 – 2005 Main Generator 6
- Figure 10: Relationship between Standard Air Flow and Discharge – Tailrace Elevation 560 – 2005 Main Generator 6
- Figure 11: Relationship between Standard Air Flow and Discharge – Tailrace Elevation 563 – 2005 Main Generator 6
- Figure 12: Relationship between Standard Air Flow and Discharge – Main Generator 6 – 2002 & 2003 – Two Original Main Vents & 2005 – Four New Main Vents Tailrace Elevation 554
- Figure 13: Relationship between Standard Air Flow and Discharge – Main Generator 6 – 2002 & 2003 – Two Original Main Vents & 2005 – Four New Main Vents Tailrace Elevation 557 and 556
- Figure 14: Relationship between Standard Air Flow and Discharge – Main Generator 6 – 2002 & 2003 – Two Original Main Vents & 2005 – Four New Main Vents Tailrace Elevation 560
- Figure 15: Relationship between Standard Air Flow and Discharge – Main Generator 6 – 2002 & 2003 – Two Original Main Vents & 2005 – Four New Main Vents Tailrace Elevation 563
- Figure 16: Relationship between Standard Airflow and Discharge – Main Generator 6 – 2002 & 2003 – Auxiliary Vents and Two Original Main Vents & 2005 – Draft Tube and Four New Main Vents – Tailrace Elevation 557 and 556
- Figure 17: Relationship between Standard Airflow and Discharge – Main Generator 6 – 2002 & 2003 – Auxiliary Vents and Two Original Main Vents & 2005 – Draft Tube and Four New Main Vents – Tailrace Elevation 560
- Figure 18: Relationship between Standard Airflow and Discharge – Main Generator 6 – 2002 & 2003 – Auxiliary Vents and Two Original Main Vents & 2005 – Draft Tube and Four New Main Vents – Tailrace Elevation 563
- Figure 19: Relationship between Standard Air Flow and Discharge – Main Generator 3 – Four Main Vents – 7/26/05

- Figure 20: Relationship between Standard Air Flow and Discharge – Main Generator 3 – Two Main Vents – 7/26/05
- Figure 21: Relationship between Standard Air Flow and Discharge – Main Generator 3 – One Main Vents – 7/26/05
- Figure 22: Relationship between Standard Air Flow and Discharge – Tailrace Elevation 556 – 2005 Main Generator 3
- Figure 23: Relationship between Standard Air Flow and Discharge – Tailrace Elevation 560 – 2005 Main Generator 3
- Figure 24: Relationship between Standard Air Flow and Discharge – Tailrace Elevation 563 – 2005 Main Generator 3
- Figure 25: Relationship between Standard Air Flow and Discharge – 2002, 2003, & 2005 Main Generator 3 – Four Main Vents – Tailrace Elevation 557 and 556
- Figure 26: Relationship between Standard Air Flow and Discharge – 2002, 2003 & 2005 Main Generator 3 – Four Main Vents – Tailrace Elevation 560
- Figure 27: Relationship between Standard Air Flow and Discharge – 2002, 2003 & 2005 Main generator 3 – Four Main Vents – Tailrace Elevation 563
- Figure 28: Relationship between Standard Air Flow and Discharge – Tailrace Elevation 556 – 2005 Main Generator 3 and 6
- Figure 29: Relationship between Standard Air Flow and Discharge – Tailrace Elevation 560 – 2005 Main Generator 3 and 6
- Figure 30: Relationship between Standard Air Flow and Discharge – Tailrace Elevation 563 – 2005 Main Generator 3 and 6
- Figure 31: Relationship between Discharge DO and Discharge – Tailrace Elevation 553 – 2005 Main Generator 6
- Figure 32: Relationship between Discharge DO and Discharge – Tailrace Elevation 556 – 2005 Main Generator 6
- Figure 33: Relationship between Discharge DO and Discharge – Tailrace Elevation 560 – 2005 Main Generator 6
- Figure 34: Relationship between Discharge DO and Discharge – Tailrace Elevation 563 – 2005 Main Generator 6
- Figure 35: Relationship between Discharge DO and Discharge – Main Generator 6 – 2002 & 2003 – Two Original Main Vents & 2005 – Four New Main Vents – Tailrace Elevation 554
- Figure 36: Relationship between Discharge DO and Discharge – Main Generator 6 – 2002 & 2003 – Two Original Main Vents & 2005 – Four New Main Vents – Tailrace Elevation 557
- Figure 37: Relationship between Discharge DO and Discharge – Main Generator 6 – 2002 & 2003 – Two Original Main Vents & 2005 – Four New Main Vents – Tailrace Elevation 560
- Figure 38: Relationship between Discharge DO and Discharge – Main Generator 6 – 2002 & 2003 – Two Original Main Vents & 2005 – Four New main Vents – Tailrace Elevation 563
- Figure 39: Relationship between Discharge DO and Discharge – Main Generator 6 -2002 & 2003 – Auxiliary Vents and Two Original Main Vents & 2005 – Draft Tube and Four New Main Vents – Tailrace Elevation 557
- Figure 40: Relationship between Discharge DO and Discharge – Main Generator 6 – 2002 & 2003 – Auxiliary Vents and Two Original Main Vents & 2005 – Draft Tube and Four New Main Vents – Tailrace Elevation 560

- Figure 41: Relationship between Discharge DO and Discharge – Main Generator 6 -2002 & 2003 – Auxiliary Vents and Two Original Main Vents & 2005 - Draft Tube and Four New Main Vents – Tailrace Elevation 563
- Figure 42: Relationship between Discharge DO and Discharge – Tailrace Elevation 556 – 2005 Main Generator 3
- Figure 43: Relationship between Discharge DO and Discharge – Tailrace Elevation 560 – 2005 Main Generator 3
- Figure 44: Relationship between Discharge DO and Discharge – Tailrace Elevation 563 – 2005 Main Generator 3
- Figure 45: Relationship between Discharge DO and Discharge – 2002, 2003 & 2005 Main Generator 3 – Four Main Vents – Tailrace Elevation 557
- Figure 46: Relationship between Discharge DO and Discharge – 2002, 2003 & 2005 Main Generator 3 – Four Main Vents – Tailrace Elevation 560
- Figure 47: Relationship between Discharge DO and Discharge – 2002, 2003 & 2005 Main Generator 3 – Four Main Vents – Tailrace Elevation 563
- Figure 48: Relationship between Discharge DO and Discharge Tailrace Elevation 556 – 2005 Main Generator 3 and 6
- Figure 49: Relationship between Discharge DO and Discharge – Tailrace Elevation 560 – 2005 Main Generator 3 and 6
- Figure 50: Relationship between Discharge DO and Discharge – Tailrace Elevation 563 – 2005 Main Generators 3 and 6
- Figure 51: Relationship between Dissolved Oxygen Increase and Air: Discharge Ratio – Main Generator 3 & 6 – 7/26/05 & 7/27/05
- Figure 52: Relationship between Aeration Efficiency and Air: Discharge Ratio – Main Generator 3 & 6 – 7/26/05 & 7/27/05
- Figure 53: Relationship between Oxygen Transfer Efficiency and Air: Discharge Ratio – Main Generator 3 & 6 – 7/26/05 & 7/27/05
- Figure 54: Relationship between Dissolved Oxygen Increase and Air: Discharge Ratio – MG 3 & 6 – 2002, 2003 & 2005
- Figure 55: Relationship between Aeration Efficiency and Air: Discharge Ratio – Main Generator 3, 4, & 6 – 2002, 2003 & 2005
- Figure 56: Relationship between Oxygen Transfer Efficiency and Air: Discharge Ratio – Main Generator 3, 4, & 6 – 2002, 2003 & 2005
- Figure 57: Relationship between Total Dissolved Gas and Air: Discharge Ratio – Main Generator 3 & 6 – 7/26/05 & 7/27/05
- Figure 58: Relationship between Total Dissolved Gas and Discharge Dissolved Oxygen – Main Generator 3 & 6 – 7/26/05 & 7/27/05
- Figure 59: Relationship between Total Dissolved Gas and Dissolved Oxygen Increase – Main Generator 3 & 6 – 7/26/05 & 7/27/05
- Figure 60: Relationship between Total Dissolved Gas and Air: Discharge Ratio – Main Generator 3, 4, & 6 – 2002, 2003 and 2005
- Figure 61: Relationship between Total Dissolved Gas and Discharge Dissolved Oxygen – Main Generator 3 & 6 – 2002, 2003 and 2005
- Figure 62: Relationship between Total Dissolved Gas and Dissolved Oxygen Increase – Main Generator 3 & 6 – 2002, 2003 and 2005

APPENDIX 2

LIST OF TABLES

Table 1: 2002 Main Generator 3 Data

Table 2: 2002 Main Generator 6 Data – Auxiliary Vents Open

Table 3: 2002 Main Generator 6 Data – Auxiliary Vents Closed

Table 4: 2003 Main Generator 3 Data

Table 5: 2003 Main Generator 6 Data

Table 6: 2005 Main Generator 6 Data

Table 7: 2005 Main Generator 3 Data

I. INTRODUCTION

AmerenUE has and continues to actively pursue technological advances to increase dissolved oxygen (DO) levels in the Bagnell Dam discharge. AmerenUE received a United States Department of Energy grant to evaluate the influences of these upgrades on aeration performance and resulting discharge DO. From 2002 through 2005 Ameren UE implemented various modifications to turbine design and operation while studying the effectiveness of these changes on discharge DO concentrations and other parameters of interest.

The hydroelectric power generation system at Bagnell Dam utilizes eight main turbines and two house turbines. In March 2002, AmerenUE replaced two turbines with new turbines designed to increase airflow, therefore enhancing aeration performance. The new turbines were installed at Main Generator 3 (MG3) and Main Generator 5 (MG5). An original turbine (Main Generator 6) was also modified at this time by installing an auxiliary venting system (ten additional vents) to enhance aeration performance. This report presents the results of these evaluations.

The following is a list of the advanced upgrades made to units 3 and 6 from 2002 to 2005 to increase DO levels. Detailed discussions of these upgrades are presented in the following paragraphs:

Main Unit 3**2002**

New turbine manufactured by American Hydro installed and in service by April 2002. The upgraded unit included four new 8-inch vent pipes and increased air passage openings through the turbine head and runner crown. A newly designed perforated nosecone with bottom plate was also installed.

2003

The bottom plate of the nose cone was removed based on results from CFD airflow modeling.

2004

No physical changes made.

2005

Check valves were removed from the four vent pipes to minimize airflow restriction.

Main Unit 6**2002**

Ten temporary auxiliary vents were installed and included in the testing.

2003

The opportunities for airflow were increased by:

- Drilling 16, 2-1/2" holes in the runner crown,
- Installing a baffle ring around the nose cone,
- Enlarging the holes in the nose cone sides,
- Re-Installing the auxiliary vents through turbine head cover.

2004

A draft tube door baffle with two 8" vent pipes was installed.

2005

The draft tube door baffle was redesigned by replacing the two 8-inch vents with single 16-inch vent.

The unit was retrofitted with four 8-inch vents and additional vent openings were drilled through the turbine head cover.

A 12-inch extension was installed on the bottom of the nose cone.

A study was conducted in August 2002 to compare the performance of a newly designed Francis turbine (MG3) to an original 1931 Francis turbine (MG6). The nosecone of MG3 was designed with numerous holes, approximately 2" in diameter, around its periphery. The intent of this nosecone design was to enhance oxygen transfer efficiency by distributing air into small bubbles. The study also included an evaluation of the auxiliary venting system at MG6. AmerenUE retained MEC Water Resources, Inc. to develop and execute a method to measure discharge aeration during a series of operating scenarios selected by AmerenUE. The study was conducted on August 13, 2002. Duplicate data at low gate settings were collected on August 15, 2002. The draft report of this study titled "Osage Project Supplemental Turbine Testing Interim Report" was issued in May 2003. The final report was submitted in December 2003.

In March 2003, Ameren modified MG3 by removing a bottom plate from the turbine's nosecone. The removal of this plate was expected to allow greater airflow into the turbine, based upon computational fluid dynamics (CFD) analysis performed by American Hydro Corporation, the manufacturer of the upgraded turbine. MG6 was also modified to increase airflow during this outage. The MG6 modification consisted of drilling holes in the runner crown, enlarging the existing holes in the nosecone sides and installing a baffle ring around the nose cone, again based upon American Hydro modeling efforts. To measure changes in turbine performance following the March 2003 modifications, the turbine evaluation procedure conducted in August 2002 was repeated on August 13, 2003.

In September 2004, AmerenUE installed vents in the draft tube of MG6 to increase venting airflow. A baffle with two eight inch vents was installed at the draft tube door. CFD analysis suggested that these relatively simple vents may significantly increase vent airflow. The MG6 auxiliary vents were also reinstalled for comparison to the draft tube vents. A study was conducted on September 7, 2004 to determine the effect of these modifications on MG6 discharge water. Results were not reported because the draft tube vent was modified shortly after the 2004 study.

During April 2005 MG6 was modified again with the retrofit of four new main vents, a redesigned draft tube vent and a nosecone extension (Figure 1). The new eight-inch main vents replaced the auxiliary vents that were used in previous studies. The new main vents are similar to the MG3 and MG5 vents and can be remotely operated, whereas the auxiliary vents were operated manually. The two draft tube vents were replaced with a single sixteen-inch vent pipe and the baffle was extended further into the draft tube. The nosecone modification was based on CFD modeling that indicated a low pressure area below the nosecone and a 12-inch nosecone extension would maximize airflow. The draft tube vent was equipped with a pneumatic butterfly valve providing remote operation capabilities. Minor modifications were also made in July 2005 to MG3, including removal of main vent check valves to reduce airflow restrictions.

This report presents the methodology, results and conclusions of the 2005 evaluation and provides a comparison to 2002 and 2003 evaluations. All of the study figures and several of the study tables are provided in separate appendices (Appendices 1 and 2, respectively) to aid report readability.

II. TURBINE EVALUATION STUDY DESIGN AND METHODOLOGY

II.A. 2005 Turbine Evaluation

The 2005 study employed a matrix (Table 1) of fifty-one operational scenarios that were comparable to previous studies measured over a two day period (July 26 and 27). The 2005 data were collected to assess turbine aeration modifications incorporated since the 2003 and 2004 evaluations. Discrete and continuous monitoring was conducted for each operational scenario. Discrete monitoring consisted of measuring:

- turbine intake vent airflow at the turbine barrels of the study units,
- DO, total dissolved gas (TDG) and temperature of discharge from study units, and
- barometric pressure at the tailrace.

Continuous monitoring consisted of measuring DO and temperature in the MG3 and MG6 intake water, as well as, air temperature and barometric pressure at the turbine barrels and draft tube of MG6.

Table 1
2005 Turbine Evaluation Study Matrix

July 26, 2005						July 27, 2005						
Run #	Gate Setting (%)	Unit Load (MW)	MG6 Draft Tube Vents	MG6 New Main Vents	Tailrace Elevation (ft)	Run #	Gate Setting (%)	Unit Load (MW)	MG3 Main Vents	MG6 Draft Tube Vents	MG6 New Main Vents	Tailrace Elevation (ft)
1	10%	1	Open	Closed	552.53	1	40%	11	4	Open	Closed	556.40
2	10%	1	Open	Open	552.48	2	40%	10	2	Open	Open	556.35
3	10%	1	Closed	Open	552.42	3	40%	11	1	Closed	Open	556.33
4	20%	3	Closed	Open	552.39	4	60%	19	1	Closed	Open	556.20
5	20%	3	Open	Closed	552.39	5	60%	18	2	Open	Open	556.23
6	30%	7	Open	Closed	552.36	6	60%	19	4	Open	Closed	556.21
7	30%	7	Closed	Open	552.37	7	85%	29	4	Open	Closed	556.17
8	40%	11	Closed	Open	552.37	8	85%	29	2	Open	Open	556.30
9	40%	11	Open	Closed	552.42	9	85%	30	1	Closed	Open	556.37
10	50%	15	Open	Closed	552.43	10	40%	10	4	Open	Closed	560.16
11	50%	15	Closed	Open	552.51	11	40%	10	2	Open	Open	560.27
12	60%	19	Closed	Open	552.58	12	40%	10	1	Closed	Open	560.21
13	60%	19	Open	Closed	552.71	13	60%	19	1	Closed	Open	560.22
14	70%	22	Open	Closed	552.79	14	60%	18	2	Open	Open	560.21
15	70%	22	Closed	Open	552.98	15	60%	20	4	Open	Closed	560.26
16	80%	25	Closed	Open	553.05	16	85%	28	4	Open	Closed	560.19
17	80%	29	Open	Closed	553.20	17	85%	28	2	Open	Open	560.00
18	90%	29	Open	Closed	553.25	18	85%	29	1	Closed	Open	560.00
19	90%	29	Closed	Open	553.36	19	40%	10	4	Open	Open	563.03
20	90%	31	Closed	Closed	553.47	20	40%	10	2	Open	Closed	563.98
21	40%	15	Closed	Closed	553.52	21	40%	10	1	Closed	Open	563.10
22	40%	13	MG2 NO VENTING		553.36	22	60%	18	1	Closed	Open	563.08
						23	60%	18	2	Open	Open	563.10
						24	60%	19	4	Open	Closed	563.12
						25	85%	27	4	Open	Closed	563.15
						26	85%	28	2	Open	Open	563.10
						27	85%	28	1	Closed	Open	563.10
						28	85%	29	None	Closed	Closed	563.29
						29	85%		None	Closed	Closed	563.00

II.A.1. Plant Operations

Control room staff made necessary adjustments to achieve the desired tailrace elevations and flow rates targeted in the study matrix. Tailrace elevations were controlled by operation of the other turbines.

Four tailrace elevations were studied as shown in Table 1. Upon reaching each of the target tailrace elevations, gates and vents for MG3 and MG6 were adjusted to the desired configuration. A low gate setting (10% providing 1MW) was only studied at the lowest tailrace elevation (552 ft MSL). The remaining gate settings were evaluated throughout the range of tailraces, including 40%, 60%, 80%, 90% and 85% gate settings (replaced 80% and 90% on Day 2). However, the higher gate settings at the 552 feet tailrace elevation could not be achieved without surpassing the target tailrace elevation. MG3 was operated with 1, 2 or 4 vents open. MG6 was operated with two original vents open continuously in conjunction with one of the following configurations: four new main vents open/draft tube vent closed, the four new main vents closed/draft tube vent open or four new main vents open/draft tube vents open.

II.A.2. Turbine Barrel and Draft Tube Vent Airflow Sampling

Airflow monitoring of MG3 and MG6 vents was performed by AmerenUE personnel. Dwyer model 640 and 641 Air Velocity Transmitters were used to measure airflow through all vents on MG3 and MG6 (including draft tube vent on MG6). Models 640 and 641 are identical in functionality, with the 640 being a slightly older model. These transmitters have an air velocity range up to 15,000 ft/min, using a heated mass flow sensor inserted into the vent pipe and held in a fixed position. The transmitter output was connected to the plant SCADA system for data collection. Raw data values were converted into velocity by post measurement processing methods.

II.A.3. Discrete Sampling

MEC Water Resources crew(s) collected DO data in the tailwater immediately downstream of the MG3 and MG6 discharges during the two-day sampling event. Day one (July 26, 2005) sampling was conducted by two crews consisting of two boats, each with three crew members. Crews measured DO, temperature and TDG at the MG3 and MG6 discharges. Tailrace elevations of 556, 560 and 563 were targeted with gates settings of 40%, 60% and 85%. MG3 venting configurations consisted of 1, 2 and 4 of the main vents open. MG6 venting configurations were: four new main vents open/draft tube vent closed, the four new main vents closed/draft tube vent open, and four new main vents open/draft tube vents open. The two original vents were open for all sampling scenarios. The day two (July 27, 2005) crew consisted of a boat with three crew members that measured DO, temperature and TDG at the MG6 discharge. Day two efforts focused on sampling MG6 discharge at tailrace elevation 553, gate settings of 10% to 90% (in increments of 10%), and for all venting configurations.

The turbine discharge was very turbulent, raising concerns that the turbulence and the presence of numerous air bubbles would interfere with DO measurement stability. A relatively large amount of DO variability was observed within the turbine discharges during prior field studies. This variability was likely influenced by the entrained air bubbles. Therefore, a sampling device was designed and constructed from PVC pipe and fittings to capture discrete samples of the turbine discharge. A diagram of the sampling device and its use is presented in Figure 2. Photographs of the devices are provided in

Figures 3 and 4. The device was submerged to collect samples at a depth of approximately 1-meter below the water surface.

Crews were equipped with water quality sondes (YSI 600 XLM sonde) and handheld data logger (YSI 650 Datalogger) to measure and store the DO measurements. TDG data were collected using Common Sensing, Inc. TBO-DL6-F TDG meter. Once it was confirmed that the target operational scenario was reached, the crews approached the outflow boil and maintained a steady position approximately 10 meters from the downstream face of the powerhouse.

TDG and DO concentrations were monitored within the sampling apparatus. Once DO readings were relatively stable, a sample was collected by lowering a sleeve over the monitors, which captured a water sample in the sampling chamber. The boat was then allowed to drift away from the dam. The water quality data sonde and TDG meter were slowly raised and lowered to prevent bubble formation on the TDG probe membrane. The DO measurements from the water in the chamber were then recorded manually every 10 seconds. Logging was stopped in three to five minutes after readings had stabilized. The crew then communicated by radio to the coordinator that the sampling run was completed.

The sampling crews were assigned to measure tailrace TDG, DO and temperature for each tailrace elevation and gate setting with the various venting configurations. Once the sampling crews confirmed collection of representative data from a sampling run, AmerenUE employees operating the turbine then altered the vent configurations. When confirmation was received that the vents were altered, the turbine discharge crews would again approach the boil, collect the discrete sample and record the corresponding measurements.

The control room raised the tailrace after crews sampled the targeted gate settings at each tailrace elevation. Tailrace elevations were modified by adjusting flow rates and number of discharging units. Tailrace elevation adjustments were completed within 5 to 30 minutes. During tailrace adjustments, the MEC Water Resources crews performed a quality control check of the monitoring equipment by comparing in-stream DO at the same location using both sondes.

Sampling resumed after confirming the next target operational scenario and completing quality control measurements. Sampling for the remaining operational scenarios followed the same procedural steps as previously described.

Index testing was performed to determine discharge rates from the units at the various tailrace elevations and gate settings. Tests were conducted by measuring the pressure across a number of taps on the discharge unit. These pressure data are collected by AmerenUE's SCADA system and later evaluated to determine discharge rates.

II.A.4. Continuous Monitoring

MEC Water Resources deployed water quality monitoring sondes within intake water flow chambers at MG3 and MG6. Intake water was collected through four equally spaced taps on the intake tube of the unit. These taps were then connected to one another and run to the PVC flow chamber. Connecting the taps into a single line was done to try to create a representative sample of the intake water. The sondes at MG 3 and MG6 were programmed to log DO and water temperature at one minute intervals for the duration of the study. Van Hessen Barologgers were placed in the MG3, MG6 turbine barrels, as well as near the draft tube of MG6. The barologgers were programmed to collect changes in pressure at one minute intervals.

II.B. Quality Assurance

MEC Water Resources developed standard operating procedures to measure discrete tailrace DO and TDG concentrations. These procedures included quality control checks to confirm instrument calibration. DO concentrations were measured with the field instrument along with a replicate instrument to check instrument calibration and consistency between the DO readings. The TDG meter was calibrated according to the manufacturer's recommendation. DO and TDG quality control measurements were recorded for later reference. After the completion of the study, measurements from the field sondes were checked against a replicate instrument.

Prior to sampling, the turbine intake data sondes were serviced and calibrated. The two YSI 600 XLM DO sondes were inserted into the flow chambers at the turbine water intakes of MG3 and MG6. The meters were recalibrated and compared to measurements from a replicate instrument. The data collected during sonde servicing were recorded on a standard datasheet for later reference. Flow chambers were checked for sufficient flow before replacing the sondes.

III. RESULTS AND DISCUSSION

The following sections present the results for each study parameter. Data are presented for the 2005 study and compared to previous study year results. In addition, DO enhancements for the two turbine designs are compared. Improvements noted during the course of the study provide empirical justification for turbine modifications at the Osage Project.

III.A. Water Temperature

Water temperature is an important variable to consider when evaluating aeration performance. The performance of an aeration device is largely driven by the difference between DO saturation and initial (intake) DO concentrations, which represents the aeration “driving force”. Therefore, aeration performance is influenced by water temperature since DO saturation concentration increases with decreasing temperature. An aeration device should entrain greater oxygen mass at lower water temperatures (higher DO saturation concentration) if all other parameters are equal (i.e., initial DO concentration, airflow, etc.). Some aeration calculations are adjusted to standard conditions (20 °C); however, other calculations typically used to evaluate turbine aeration performance are not standardized. Therefore, the potential influence of water temperature should be considered when evaluating these measurements of aeration performance.

Annual temperature variability in Osage Project discharges are explained by lake mechanisms. Timing of reservoir stratification is the major factor that influences summer discharge water temperature. The temperature of the hypolimnion is primarily driven by timing of stratification, with earlier stratification resulting in cooler hypolimnetic temperatures. Therefore, earlier stratification results in cooler summer Osage Project discharges since the hypolimnion is the primary discharge water source,

III.A.1. Water Temperature - 2005

Temperature data were recorded in the discharge water from both study turbines in 2005. Discharge temperature from both units ranged from approximately 25 to 27 °C. Discharge water temperature increased with increasing tailrace and gate setting. Increasing tailrace elevation is directly related to total Project discharge, while individual turbine discharge is directly related to gate setting. Near-field reservoir stratification is somewhat destabilized as Project and individual turbine discharge increases. This results in withdrawal of warmer metalimnetic water rather than solely withdrawing from the hypolimnion (deep, cool layer). Therefore, discharge temperature increases as flow rates increase.

III.A.2. Water Temperature Comparison of Study Years

Study results from 2002 and 2005 are directly comparable without temperature compensation due to similar water temperatures. Discharge water temperatures were nearly identical during the 2002 and 2005 study conditions, ranging from 24 to 26 °C and 24 to 27 °C, respectively. However, comparison of the 2002 and 2005 results to the 2003 results may be more complicated since discharges were cooler during the 2003 study, ranging from 18 to 21 °C. Cooler 2003 discharges are explained by the observed earlier onset of stratification and resulting cooler hypolimnion. The difference in DO saturation concentrations between 2003 and the other study years is approximately 1 mg/L, representing a difference between intake and saturation DO (driving force) of

approximately 15%. The differences in aeration performance were potentially caused by the temperature differences in 2002, 2003 and 2005, for which discharge DO concentrations were well below saturation. However, these differences are likely within the range of instrument accuracy and sampling representativeness, which makes the influence of temperature between 2003 and the remaining study years difficult to discern.

III.B. Airflow

Airflow is a measure of the amount of air passing through the venting system over a given period of time. Each of the Osage Project's eight main generating units is equipped with some type of venting system to enhance discharge DO conditions. Airflow measurements were performed during all turbine tests since aeration performance is directly related to this critical parameter. Air temperature and barometric pressure were also measured in the turbine barrel and draft tube areas of MG6 and MG3 for conversion of airflow readings to standard atmospheric conditions. The volume of airflow may also be compared to the discharge rate, expressed as the air:discharge ratio. Air:discharge ratios provide a means of comparing the relationship of airflow and discharge using one value. This ratio is typically considered an important parameter for venting turbines. The following sections present airflow results from various venting and discharge configurations.

III.B.1. Main Generator 6 Airflow - 2005

Turbine intake airflow was measured at MG6 for each operating scenario with three different venting configurations: 1) four new main vents open and draft tube vent closed; 2) four new main vents open and draft tube vent open; and 3) four new main vents closed and draft tube vent open. The original two main vents were open during all operating scenarios and vent configurations at MG6, however, they did not contribute significantly to total airflows. Airflow data for MG6 are presented as Figures 5 through 7 illustrated by vent configuration and as Figures 8 through 11 illustrated by tailrace.

Airflow for all vent configurations decreased with increasing tailrace elevation at corresponding gate settings (Figures 5 through 7). MG6 operated with only the draft tube vents open exhibited the greatest range of decrease. At tailrace 553 and gate setting of 60% airflow was 12,400 scfm while the same gate setting at 563 tailrace elevation produced minimal airflow (Figure 5). In contrast, MG6 with only the new main vents open had the least change in airflow over the range of tailrace elevations, with a change of approximately 3,000 to 5,000 scfm from tailrace elevation 553 to 563 at 40 to 85% gate settings (Figure 6). With this vent configuration, airflow was similar at 560 and 563 tailrace elevations for all gate settings with the new main vents.

Use of the new main vents and draft tube vents individually produced opposite relationships between airflow and discharge (Figures 9 to 11). Airflow through the new main vents decreased with increasing discharge, whereas airflow through the draft tube vent increased with increasing discharge. The draft tube vent produced greater airflow at low tailrace elevations (553, 556) for all gate settings. At higher tailrace elevations, the draft tube vent was only effective at the highest gate setting. The new main vents produced greater airflow at the low gate settings at tailrace elevations 560 and 563.

The combination of the new main vents and the draft tube vents produced the greatest amount of total airflow for all MG6 configurations of gate settings and tailrace elevations (Figures 8 to 11). The differing relationships between airflow and discharge for the new main vents and draft tube vent resulted in enhanced airflow when used in combination. Essentially, one vent system was effective when the other was not, producing significant aeration capacities through most operating ranges. Airflow was greatest at 556 tailrace 60% gate (10,500 scfm) when MG6 was operated with both vent modifications. Airflow at this tailrace and gate setting was approximately 1,000 scfm greater than the draft tube vent operating solely and 6,000 scfm greater than the new main vents operating solely. Airflow was only measured at one point for draft tube and new main vents at tailrace 553, which was comparable to the other vent configurations.

III.B.2. Main Generator 6 Airflow - Comparison of Study Years

MG6 was operated with various vent configurations during the 2002, 2003 and 2005 studies. The 2002 and 2003 studies were conducted with similar venting systems comprised of ten temporary (manual) auxiliary vents. However, the 2005 study was conducted with an automated vent system in place which employed four new main vents and a draft tube door baffle with a 16" vent pipe. The two original main vents were open throughout all study years and vent configurations. During 2002 and 2003 studies airflow was collected manually using handheld pitot tubes and manometers; however, in 2005 fixed position air velocity transmitters were mounted within the vents. Data collected by the air velocity transmitters were logged by Ameren's SCADA system. The fixed position transmitters improved measurement accuracy.

Airflow through the MG6 main vents generally increased each study year (Figures 12 through 15). Improvements from 2003 to 2005 were expected with the addition of four new main vents. Airflow with the auxiliary vents closed (AVC) was greater in 2003 than those observed in 2002 for all turbine scenarios. This increase resulted from upgrades performed to the MG6 nosecone (holes were enlarged and a baffle ring was installed) prior to the 2003 study. MG6 airflow was greater in 2005 with the four new main vents than in 2002 for all similar gate settings and tailrace elevations. However, airflows observed with the four new main vents in 2005 were only significantly different than those in 2003 at the 554 tailrace elevation. Airflow data collected at the remaining tailrace elevations were not appreciably different between the study years.

Airflow from the optimal vent configurations increased each study year (Figures 16 through 18). These configurations included use of the main and auxiliary vents during 2002 and 2003 and main and draft tube vents in 2005. The increase from 2002 to 2003 is again explained by modifications to the nosecone. The improvement observed in 2005 is attributed to complimentary venting capacity of the main and draft tube vents throughout the range of tailraces and discharges.

III.B.3. Main Generator 3 Airflow - 2005

MG3 airflow was measured on the second day of sampling and for three different venting configurations: 1) four main vents open; 2) two main vents open; and 3) one main vent open. MG3 airflow and discharge data for the 2005 study year are depicted in Figures 19 through 21 for each vent configuration, while data for each tailrace are presented in Figures 22 through 24. Airflows ranged from 7,600 scfm to 2,500 scfm through four main vents, 6,900 scfm to 2,500 scfm through two main vents and from 4,700 to 2,100 scfm through one main vent.

Airflow through two and four main vents was similar for all tailrace elevations and gate settings, indicating that vent capacity is not typically limiting airflow. The greatest difference between the four and two main vent scenarios occurred at 556 tailrace elevation at gate settings of 40 and 60 % (Figure 22). All vent configurations yielded similar airflows at the highest tailrace elevation regardless of gate setting (Figure 24).

MG3 air: discharge ratios were similar for the four and two vent configurations throughout the study, but were only slightly depressed at tailrace 553 for the one main vent configuration.

III.B.4. Main Generator 3 Airflow - Comparison of Study Years

Relatively minor turbine modifications were made to MG3 during the study years. The most notable modification was the removal of the nosecone bottom plate prior to the 2003 study. Vent check valves were removed prior to 2005 testing. Airflow data collected during the three study years are presented in Figures 25 to 27.

Airflow was most notably improved by removal of the nosecone bottom plate as suggested by increased airflow from 2002 to 2003. MG3 airflow was particularly greater at moderate to high gate settings. The most significant increase occurred at tailrace 556 which averaged approximately 1,000 scfm for all gate settings (Figure 25). The 2003 and 2005 airflow data are relatively similar at all gate settings and tailrace elevation. Therefore, the removal of check valves from the four main vent pipes in 2005 apparently had little effect on airflow. This observation is also corroborated by the similar airflows with 2 and 4 vents open in 2005. Both observations suggest that airflow is not limited by vent capacity. Airflow is more likely limited by dynamics within the turbine as indicated by increased airflow with nosecone bottom plate removal.

III.B.5. Main Generators 3 and 6 Airflow Comparison - 2005

MG 6 operating with the draft tube and new main vents produced greater airflow than MG3 operating with four main vents at low tailrace elevations (Figure 28). However, MG6 and MG 3 exhibited similar airflows at low to moderate gate settings (40 to 60 %) and moderate to high tailrace elevations (560 -563) (Figures 29 and 30). MG3 operating with four main vents provided greater airflow at the high gate setting (85%) and moderate to high tailrace elevations.

III.C. Dissolved Oxygen

Dissolved oxygen is the concentration of gaseous oxygen entrained in a liquid and is essential for survival of aquatic life. It can be measured in various ways, for these studies it was measured using a rapid pulse DO probe. The results of DO measurements collected in the discharge waters of the Osage Project are described in the following sections.

III.C.1. Main Generator 6 Dissolved Oxygen - 2005

Turbine discharge DO concentrations typically decreased for all MG6 vent configurations with increasing tailrace elevation and discharge (Figures 31 to 34). The main exception to this observation was the draft tube vent only configuration at high tailrace elevations (560 and 563). At these operational settings, MG6 discharge DO increased with discharge, which is verified by higher airflows with increased discharge at the tailrace conditions.

During the 2005 study, MG6 discharge DO ranged from 2.60 to 7.52 mg/L (Tables 2 and 3) with the lowest DO recorded at tailrace 560, 85% gate, with only the new main vents in operation. The highest reading was recorded at tailrace 553, 20% gate using the draft vent only. The four new main vent DO readings ranged from 2.6 to 7.4 mg/L, draft tube vent only DO levels were 2.8 to 7.5 mg/L, while the combination of the two yielded DO concentrations of 3.7 to 7.1 mg/L. DO was typically above the 5 mg/L criterion at tailrace elevations below 560 ft. MSL.

Table: 2
Summary of 2005 Discharge Dissolved Oxygen Concentration Data (7/26/05)

Tailrace Elev. (feet)	Gate Setting (%)	Vent Configurations			Discharge (cfs)		Dissolved Oxygen (mg/L)	
		MG6		MG3				
		Draft Tube Vent	New Main Vents	# of Main Vents Open	MG6	MG3	MG6	MG3
556	40%	Open	Closed	4	1,800	1,784	5.54	5.95
556	40%	Open	Open	2	1,800	1,784	5.59	5.98
556	40%	Closed	Open	1	1,800	1,784	5.35	5.53
556	60%	Closed	Open	1	2,796	2,760	4.43	4.72
556	60%	Open	Open	2	2,796	2,760	5.73	5.20
556	60%	Open	Closed	4	2,796	2,760	5.48	5.50
556	85%	Open	Closed	3	4,136	4,185	4.87	4.69
556	85%	Open	Open	2	4,136	4,185	5.05	4.80
556	85%	Closed	Open	1	4,136	4,185	3.12	4.15
560	40%	Open	Closed	4	1,792	1,767	3.03	4.66
560	40%	Open	Open	2	1,792	1,767	4.95	4.86
560	40%	Closed	Open	1	1,792	1,767	4.7	4.29
560	60%	Closed	Open	1	2,780	2,745	4.05	4.01
560	60%	Open	Open	2	2,780	2,745	5.17	4.44
560	60%	Open	Closed	4	2,780	2,745	3.34	4.82
560	85%	Open	Closed	4	4,059	4,184	3.69	4.82
560	85%	Open	Open	2	4,059	4,184	3.7	4.61
560	85%	Closed	Open	1	4,059	4,184	2.6	4.02
563	40%	Open	Open	4	1,765	1,755	4.5	4.20
564	40%	Open	Closed	2	1,765	1,755	2.85	4.04
563	40%	Closed	Open	1	1,765	1,755	4.29	4.06
563	60%	Closed	Open	1	2,747	2,745	4.29	3.95
563	60%	Open	Open	2	2,747	2,745	4.84	4.86
563	60%	Open	Closed	4	2,747	2,745	3.33	4.57
563	85%	Open	Closed	4	3,980	4,179	3.78	4.47
563	85%	Open	Open	2	3,980	4,179	3.84	4.24
563	85%	Closed	Open	1	3,980	4,179	3.27	3.86
563	85%	Closed	Closed	None	3,980	4,179	3.34	3.36
563	85%	Closed	Closed	None	3,980	4,179	3.04	2.52

Table: 3
Summary of 2005 Discharge Dissolved Oxygen Concentration
Data (7/27/05)

Tailrace Elev. (feet)	Gate Setting (%)	MG6 Vent Configurations		MG6 Discharge (cfs)	MG6 Dissolved Oxygen (mg/L)
		Draft Tube Vent	New Main Vents		
553	10%	Open	Closed	409	6.80
552	10%	Open	Open	409	7.07
552	10%	Closed	Open	409	7.29
552	20%	Closed	Open	818	7.41
552	20%	Open	Closed	818	7.52
552	30%	Open	Closed	1,260	6.94
552	30%	Closed	Open	1,260	6.59
552	40%	Closed	Open	1,758	6.29
552	40%	Open	Closed	1,758	6.67
552	50%	Open	Closed	2,239	6.44
553	50%	Closed	Open	2,239	5.33
553	60%	Closed	Open	2,779	4.84
553	60%	Open	Closed	2,779	6.38
553	70%	Open	Closed	3,350	6.15
553	70%	Closed	Open	3,350	4.45
553	80%	Closed	Open	3,947	3.97
553	80%	Open	Closed	3,947	5.40
553	90%	Open	Closed	4,344	5.27
553	90%	Closed	Open	4,344	3.64
553	90%	Closed	Closed	4,344	2.42
554	40%	Closed	Closed	1,758	2.18

The maximum DO levels for all three vent configurations occurred at low tailrace and gate settings. Minimum DO values were recorded at tailrace 560 and 85% gate for new main vents and the combination of new main vents and the draft tube vent, while the draft tube vent alone exhibited a minimum DO occurring at 563 and 40% gate.

As seen with airflow, the relationship between DO and discharge at high tailrace elevations were opposite for the new main vents and the draft tube vent only. The new main vent configuration resulted in higher DO levels at the lower gate settings, while the draft tube vent produced higher DO levels as discharge increased. The draft tube only scenario produced DO concentrations equal to the combination of the new main vents and the draft tube vent at 85% gate for 560 and 563 tailrace elevations. When operated together, the new main vents and draft tube vent were most effective at the 60% gate settings.

III.C.2. Main Generator 6 Dissolved Oxygen - Comparison of Study Years

In addition to vent airflow, turbine discharge DO levels may be influenced by intake water temperature and DO concentration. As discussed earlier, aeration performance is greater at lower water temperature since DO saturation increases with decreasing temperature. Also, discharge DO increases with initial (intake) DO concentrations. As previously discussed, water temperatures were very similar in 2002 and 2005 and markedly cooler (5 °C) in 2003. The cooler intake temperature in 2003 was due to earlier stratification which set the hypolimnetic temperature cooler than in 2002 and 2005. The cooler 2003 hypolimnetic temperature represented stronger reservoir stratification, which in turn limited the withdrawal of warmer and more oxygenated metalimnetic water during high discharges. Maximum intake DO concentrations during 2002 and 2005 were quite similar (1.1-1.2 mg/L), whereas maximum intake DO in 2003 was 0.5 mg/L. The 2003 intake conditions represent conflicting variables on aeration performance. While lower intake temperature increases aeration efficiency, lower intake DO reduces discharge DO. Since these factors potentially counteract each other in this instance, the 2003 data are likely comparable to the 2002 and 2005 data particularly considering the inherent variability resulting from instrument accuracy and sampling representativeness.

In all study years, discharge DO concentrations with the main vent configuration decreased with increasing tailrace elevations and discharge (Figures 35 to 38). These observations were based upon use of the two original main vents during 2002 and 2003 and operation of the four new main vents in 2005. Dissolved oxygen was greater during 2003 than 2002 for all gate settings and tailrace elevations below 563. In 2003, DO levels at tailrace elevation 563 were less than those observed at similar gate settings in 2002. The 2005 DO concentrations for MG6, operating with four new main vents, were greater than 2002 and 2003, operating with the two original main vents for all tailrace elevations. For these vent configurations, airflow during 2005 was similar to 2003 so the higher 2005 discharge DO levels at high tailrace elevations were likely due to higher intake DO conditions

Discharge DO concentrations for 2002 and 2003 with main and auxiliary vents open are compared to those observed during 2005 both draft tube and four new main vents (Figures 39 to 41). DO levels in 2003 were higher than in 2002 with the same venting configuration, at tailrace elevations 557 and 560. However, 2002 DO levels were greater than in 2003 at tailrace elevation 563, again potentially due to higher intake DO levels. The 2005 data demonstrate that MG6 discharge DO concentrations improved markedly with these vent configurations as compared to the 2002 and 2003 data.

DO concentrations observed in the discharge of MG6 had significant increases from the unit's conventional venting system. Table 4 describes the increases in DO levels measured with the two original main vents in 2002 and both draft tube and new main vents in 2005. Concentrations increased an average of 1.9 mg/L from 2002 to 2005 with the greatest gain occurring at the low tailrace, high gate setting configuration.

**Table 4: Main Generator 6 Discharge Dissolved Oxygen Enhancement
from 2002 to 2005**

Tailrace Elevation (ft. MSL)	Discharge Dissolved Oxygen (mg/L)								
	2002			2005			Difference (2005-2002)		
	Gate Setting			Gate Setting			Gate Setting		
	40%	60%	80% & 90%	40%	60%	85%	40%	60%	85%
556	3.90	3.11	2.04	5.59	5.73	5.05	1.69	2.62	3.02
560	3.01	3.05	2.00	4.95	5.17	3.70	1.94	2.12	1.71
563	3.61	3.28	2.60	4.50	4.84	3.84	0.89	1.56	1.25

Discharge DO concentrations for 2002 were typically above the DO criterion of 5 mg/L at tailrace elevation 552 and for several of the lower gate settings at tailrace elevations 554, 557 and 560 (Appendix 2, Tables 2 and 3). Discharge DO levels at tailraces 560 and 563 were typically below the DO criterion. The DO criterion was achieved in discharge water at tailraces 552 and 554 at 1 megawatt gate settings, all other gate settings and tailrace elevations yielded DO levels below the criterion (Appendix 2, Table 5). Discharge DO levels in 2005 were greater than 5 mg/L at tailrace elevations below 560 with the exception of the four new main vent configuration (Appendix 2, Table 6). The four new main vents operating alone produced DO concentrations below the criterion at tailraces and gate settings above 553 and 60%, respectively.

III.C.3. Main Generator 3 Dissolved Oxygen - 2005

Discharge DO levels from MG3 were relatively similar for the two and four main vent configurations (Figures 42 through 44). Discharge DO concentrations from the four vent configuration ranged from 4.2 to 6.0 mg/L (Table 2), with minimums occurring at 40% gate and 563 tailrace and maximums occurring at 40% gate and 556 tailrace elevations. The two vent configuration resulted in discharge DO values of 4.0 and 6.0 mg/L. Maximums and minimums were recorded at the same gate settings and tailrace elevations as the four vent configuration. Discharge DO values for two and four vents were above the DO criterion for 40% and 60% gate settings at 556 tailrace elevations, with the remainder of the configurations yielded DO levels less than 5 mg/L.

Discharge DO levels observed with one main vent open were lower than the four and two vent configurations throughout the testing. One main vent DO readings ranged from 3.9 to 5.5 mg/L. Maximum values were observed at 40% gate at tailrace 556 while minimums occurred at the highest gate and tailrace configurations. At the highest tailrace elevation (563), discharge DO levels were similar for all gate settings. One main vent produced a similar comparison regarding the DO criterion as two and four main vents.

III.C.4. Main Generator 3 Dissolved Oxygen - Comparison of Study Years

DO concentrations for 2002 were less than those observed in 2003 and 2005 at all turbine configurations (Figures 45 through 47). The 2005 discharge DO concentrations were similar to 2003 values at tailrace 556 for all gate settings and at low gate settings for the higher tailrace elevation. At higher tailrace elevations and gate settings, 2005 DO concentrations were greater than those observed during 2003. The higher discharge DO concentrations observed at the higher tailraces and gate settings in 2005 were likely due to lower 2003 intake DO concentrations.

DO enhancement modifications performed on MG3 produced an average gain in DO concentrations of 1.4 mg/L (Table 5). DO levels had the greatest gains at the moderate to high gate settings for all tailrace elevations.

Table 5: Main Generator 3 Discharge Dissolved Oxygen Enhancement from 2002 to 2005

Tailrace Elevation (ft. MSL)	Discharge Dissolved Oxygen (mg/L)								
	2002			2005			Difference (2005-2002)		
	Gate Setting			Gate Setting			Gate Setting		
	40%	60%	80% & 90%	40%	60%	85%	40%	60%	85%
556	5.02	4.10	3.12	5.95	5.50	4.69	0.93	1.40	1.57
560	3.63	3.21	2.60	4.66	4.82	4.82	1.03	1.61	2.22
563	3.49	3.39	2.92	4.20	4.57	4.47	0.71	1.18	1.56

Discharge DO concentrations during the three study years were typically above the DO criterion (5 mg/L) when tailrace elevations were below 560 (Appendix 2, Tables 1, 4 and 7). DO levels in 2002 went below 5 mg/L when gate settings were 80% at tailrace elevation 554 with the exception of the lowest gate settings at tailrace 557.

III.C.5. Main Generator 3 and 6 Dissolved Oxygen Comparison - 2005

Dissolved oxygen followed a similar pattern as airflow when comparing MG6 draft tube and new main vents to MG3 four main vent configurations (Figures 48 to 50 and Table 6). However, increased DO produced by greater MG6 airflows at low tailrace and moderate to high gate settings was marginal. Observed DO increases were within the margin of accuracy of the test method. Discharge DO from MG3 was more consistent with increasing gate setting than MG6 and provided greater DO at high gate settings and moderate to high tailrace elevations. These discharge DO increases ranged from 0.6 to 1.1 mg/L.

Table 6: Main Generators 3 and 6 Discharge Dissolved Oxygen Comparison - 2005

Tailrace Elevation (ft. MSL)	Discharge Dissolved Oxygen (mg/L)								
	MG3			MG6			Difference		
	Gate Setting			Gate Setting			Gate Setting		
	40%	60%	85%	40%	60%	85%	40%	60%	85%
556	5.95	5.5	4.69	5.59	5.73	5.05	0.36	-0.23	-0.36
560	4.66	4.82	4.82	4.95	5.17	3.70	-0.29	-0.35	1.12
563	4.2	4.57	4.47	4.50	4.84	3.84	-0.30	-0.27	0.63

*** Negative values indicated that MG6 DO was greater than MG3.

III.D. Aeration Performance

Various relationships can be established using turbine discharge, airflow, and DO data collected during testing of the study units. These relationships may be used to guide design criteria for future aeration enhancements. Several equations have been developed to allow comparison of aeration data and are described below.

The DO concentration increase attributed to turbine aeration is determined by subtracting the intake DO concentration (C_L) from the discharge concentration C_D).

$$\text{DO increase} = C_D - C_L$$

Aeration efficiency is measurement of a study unit's ability to increase the discharge DO concentration to saturation at a given operational scenario. This value accounts for varying temperatures between data sets, since DO saturation is related to water temperature. This calculated value is also closely related to DO increase since the calculation serves as the numerator. Aeration efficiency is calculated by dividing DO increase ($C_D - C_i$) by the difference between the saturation concentration (C_s) of oxygen and the intake DO concentration (C_i) or $C_s - C_i$.

$$\text{Aeration efficiency} = \frac{(C_D - C_i)}{(C_s - C_i)}$$

Oxygen transfer efficiency (OTE) is a measure of a unit's ability to transfer oxygen vent air into the turbine discharge. OTE is defined as the percentage of the available oxygen in the airflow that dissolves into the turbine discharge. This value is calculated by dividing the mass of the oxygen transferred to the water by the mass of the oxygen passing through the vent.

$$\text{OTE} = \frac{\text{mass O}_2 \text{ (lbs) transferred to discharge water}}{\text{mass of O}_2 \text{ (lbs) from airflow}}$$

III.D.1. Aeration Performance - 2005

MG6 and MG3 DO increase values show a similar trends with air:discharge ratio for all configurations (Figure 51). The relationship between DO increase and air:discharge ratio was essentially linear between air:discharge ratios of 0.00 and 0.07. DO increase exceeded the 5 mg/L water quality criterion for both units primarily when air: discharge ratios exceeded 0.05, while DO increase was not greatly influenced by air: discharge ratios greater than 0.10.

As with other study years, calculated DO increase was approximately 2 mg/L, when very little or no venting airflow was provided. These observations may only be explained by misrepresentative intake DO sampling, inaccurate intake DO monitoring, and/or aeration that occurs within the turbulent boil area. Intake DO could be underestimated if water flow is stratified within the intake and disproportionate sampling occurs, such as sampling of the cooler, anoxic bottom strata within the intake. DO monitoring of relatively anoxic conditions is very challenging since calibration is performed at saturated conditions rather than test conditions and hydrogen sulfide, which is typically found to some extent in anoxic environments, may also interfere with dissolved oxygen

measurements. Lastly, the turbine boil is quite turbulent, particularly at high discharges (gate settings, which could result in aeration within the boil.

DO increase ranged from 2.1 to 2.2 mg/L during four tests when MG6 turbine vents were closed. These tests were conducted at moderate to high gate settings (40% to 90%) and low and high tailrace elevations (553 and 563). If misrepresentative sampling occurred, lower DO increase would be expected at lower study unit discharge (lower gate setting) and lower Project discharge (lower tailrace), as reservoir stratification would be less disturbed and less metalimnetic water would be withdrawn. However, the MG6 DO increase was consistent between these discharge scenarios. MG3 DO increase during no venting at a high gate setting (85%) and tailrace elevation (563) ranged from 0.7 to 1.4 mg/L. During no venting runs, discharge temperature was similar to recorded intake temperature at MG6 (moderate to high gate setting and low tailrace) and at MG3 no venting, (high gate setting and tailrace), suggesting representative intake sampling since oxygenated metalimnetic water would be warmer than anoxic hypolimnetic water. However, MG6 discharge temperature was approximately 1.4 °C warmer than recorded intake temperature during the high gate setting, high tailrace no venting testing. These observations do not demonstrate that any one factor is responsible for the recorded DO increases with no venting, suggesting that all factors discussed above may influence these observations.

A clear correlation between aeration efficiency and air: discharge ratio was observed when all turbine testing data are compared (Figure 52). Aeration efficiency shares a similar relationship as DO increase to air: discharge ratio since the parameter is calculated using the observed DO increase and water temperature does not vary significantly between test scenarios. As with DO increase, aeration efficiency is not appreciably influenced by air:discharge ratios greater than 0.10.

Calculated OTE (percentage of oxygen dissolved in discharge water) decreased as air: discharge ratio increased (Figure 53). Air:discharge ratios less than 0.05 had the greatest influence on OTE, with diminishing return for additional airflow at ratios greater than 0.10.

III.D.2. Aeration Performance - Comparison of Study Years

DO increase was similar for 2005 and 2003, with both years showing a strong relationship to air: discharge ratios (Figure 54). The 2002 DO increase data were more scattered, particularly at higher air: discharge ratios when greater variation was observed in all datasets. The 2002 deviations could be attributed to the methods used to collect airflow in 2002. DO Increase for 2003 began to deviate from the group when air to discharge ratios reach 0.06. Relationships between air: discharge ratio and DO increase in 2005 were more consistent than 2002 and 2003 at higher air: discharge ratios. The better 2005 correlation may be explained by the more accurate airflow measurement techniques used in 2005, particularly at high airflows (high velocity) when measurement errors are magnified. Net DO transfer exceed 5 mg/L at air: discharge ratios of 0.05 relatively consistently between study years.

The relationship between aeration efficiency and air: discharge ratio exhibited a similar pattern as DO increase due to its dependency on DO transfer (Figure 55). Again, the 2002 and 2003 relationships are scattered above air: discharge ratios of 0.06. The 2005

data follow a much more consistent relationship throughout the range of air: discharge ratios. Data for all years were similar at air: discharge ratios of less than 0.05

Observations of OTE during all study years showed a consistent relationship with air: discharge ratio, regardless of the study turbine or vent configuration (Figure 56). These observations indicate that OTE is closely related to the air: discharge relationship, the driving factor in the aeration of discharge water. OTE decreases sharply with air:discharge ratios from 0 to 0.10. An inflection point is reached when air: discharge ratios exceed 0.10, indicating a point of diminishing return for additional aeration past this point.

III.E. Total Dissolved Gas

Total dissolved gas is the sum of the partial pressures of gases in water, consisting primarily of nitrogen and oxygen. TDG is increased with aeration, particularly when atmospheric air is used as the oxygen source since additional nitrogen is dissolved in water along with oxygen. TDG is an important parameter when considering aeration systems because excessive levels of TDG can be detrimental to aquatic life, leading to gas bubble disease. The Missouri TDG water quality criterion for protection of aquatic life is 110% of the saturation partial pressure. TDG is measured using the membrane diffusion method which employs a pressure transducer and a gas membrane tube that is permeable to all gases as well as water vapor. As dissolved gases pass through the tubing the sum of their pressures is measured by a pressure transducer resulting in a measurement of TDG pressure. Percent saturation can then be calculated dividing the TDG by the barometric pressure. The following paragraphs describe the observations recorded in the discharge water of MG6 and MG3 throughout the study years.

III.E.1. Total Dissolved Gas - 2005

TDG concentrations were typically highest at the low tailrace elevations and discharge rates since greater aeration occurs at these operational scenarios. As tailrace and discharge rates increased, TDG decreased (Table 7). For the configuration of MG6 with the new main vents operating, TDG measurements ranged from 92% at the tailrace elevation 563 and a discharge of 4200 cfs, while the maximum value of 121% was measured at tailrace elevation 553 and a discharge of 706 cfs. For MG6 operating with draft tube vent, TDG values ranged from 120% at tailrace elevation 553 and a discharge of 694 cfs and 95% at tailrace elevation 563 with a discharge of 1,810 cfs. TDG levels discharged by MG6 with the draft tube and main vents open ranged from 98 to 118%, with the 110% criterion exceeded in 60% of scenarios and until high gate setting (85%) and high tailrace (560') was reached. For MG3, TDG maximum values were 115% at tailrace elevation 556 and 1,788 cfs discharge (2 main vents) and at tailrace 556 with 2,600 cfs discharge (4 main vents). The minimum of 102% was observed at tailrace elevation 563 and with 4,000 cfs discharge with one main vent open.

TDG increased with air: discharge ratio, typically exceeding 110% when air: discharge ratios reached 0.05 regardless of turbine or vent configuration (Figure 56). Air: discharge ratios had little affect on TDG after 0.10, similar to DO observations. Figures 57 and 58 illustrate the relationship between TDG and dissolved oxygen values. The TDG criterion of 110% was generally exceeded after the DO water quality criterion of 5 mg/L and a DO increase of 4.5 mg/L was exceeded

MEC Water Resources, Inc.

Osage Project Supplemental Turbine Testing Report

Table 7: Total Dissolved Gas - 2005

Run #	Gate Setting (%)	Tailrace Elevation (ft)	Unit Load (MW)		MG 6 Draft Tube Vents	MG 6 New Main Vents	MG 3 Main Vents Open	Unit Discharge (cfs)		Total Dissolved Gas (% Saturation)	
			MG 6	MG 3				MG 6	MG 3	MG 6	MG 3
August 27, 2005											
1	10%	552.5	1	---	Open	Closed	---	157	---	117	---
2	10%	552.5	1	---	Open	Open	---	166	---	118	---
3	10%	552.4	1	---	Closed	Open	---	156	---	119	---
4	20%	552.4	3	---	Closed	Open	---	706	---	121	---
5	20%	552.4	3	---	Open	Closed	---	694	---	120	---
6	30%	552.4	7	---	Open	Closed	---	1,279	---	116	---
7	30%	552.4	7	---	Closed	Open	---	1,276	---	116	---
8	40%	552.4	11	---	Closed	Open	---	1,841	---	117	---
9	40%	552.4	11	---	Open	Closed	---	1,838	---	118	---
10	50%	552.4	15	---	Open	Closed	---	2,394	---	117	---
11	50%	552.5	15	---	Closed	Open	---	2,374	---	111	---
12	60%	552.6	19	---	Closed	Open	---	2,934	---	108	---
13	60%	552.7	19	---	Open	Closed	---	2,971	---	117	---
14	70%	552.8	22	---	Open	Closed	---	3,559	---	115	---
15	70%	553.0	22	---	Closed	Open	---	3,581	---	107	---
16	80%	553.1	25	---	Closed	Open	---	4,181	---	103	---
17	80%	553.2	29	---	Open	Closed	---	4,114	---	110	---
18	90%	553.3	29	---	Open	Closed	---	4,353	---	110	---
19	90%	553.4	29	---	Closed	Open	---	4,381	---	101	---
20	90%	553.5	31	---	Closed	Closed	---	4,409	---	94	---
21	40%	553.5	15	---	Closed	Closed	---	1,928	---	94	---
August 26, 2005											
1	40%	556.4	11	9	Open	Closed	4	1,826	1,779	113	108
2	40%	556.4	10	9	Open	Open	2	1,796	1,788	114	115
3	40%	556.3	11	9	Closed	Open	1	1,809	1,797	113	113
4	60%	556.2	19	16	Closed	Open	1	2,936	2,643	109	110
5	60%	556.2	18	15	Open	Open	2	2,904	2,611	115	114
6	60%	556.2	19	15	Open	Closed	4	2,957	2,600	115	115
7	85%	556.2	29	25	Open	Closed	3	4,301	3,932	111	111
8	85%	556.3	29	26	Open	Open	2	4,314	3,953	111	109
9	85%	556.4	30	27	Closed	Open	1	4,357	4,022	100	107
10	40%	560.2	10	8	Open	Closed	4	1,773	1,741	102	112
11	40%	560.3	10	8	Open	Open	2	1,781	1,750	113	115
12	40%	560.2	10	8	Closed	Open	1	1,786	1,757	111	109
13	60%	560.2	19	15	Closed	Open	1	2,940	2,612	106	107
14	60%	560.2	18	15	Open	Open	2	2,934	2,598	112	111
15	60%	560.3	20	15	Open	Closed	4	3,009	2,588	100	112
16	85%	560.2	28	25	Open	Closed	4	4,262	3,918	103	110
17	85%	560.0	28	26	Open	Open	2	4,297	3,945	102	110
18	85%	560.0	29	27	Closed	Open	1	4,284	4,010	94	107
19	40%	563.0	10	6	Open	Open	4	1,705	1,723	108	109
20	40%	564.0	10	6	Open	Closed	2	1,809	1,710	95	109
21	40%	563.1	10	6	Closed	Open	1	1,734	1,693	106	109
22	60%	563.1	18	15	Closed	Open	1	2,862	2,594	105	105
23	60%	563.1	18	14	Open	Open	2	2,889	2,576	107	110
24	60%	563.1	19	14	Open	Closed	4	2,963	2,575	95	109
25	85%	563.2	27	25	Open	Closed	4	4,195	3,945	96	105
26	85%	563.1	28	25	Open	Open	2	4,187	3,947	98	104
27	85%	563.1	28	26	Closed	Open	1	4,214	4,000	93	102
28	85%	563.3	29	29	Closed	Closed	None	4,195	4,110	93	93
29	85%	563.0			Closed	Closed	None	4,209	4,100	92	92

III.E.2. Total Dissolved Gas - Comparison of Study Years

TDG observations during all study years followed a similar relationship with air: discharge ratio (Figure 59). However, the 2002 TDG observations were lower and more scattered than those observed during 2003 and 2005 at air: discharge ratios above 0.05. This is likely attributed to instrumentation differences 2002 (Hydrolab TDG probe) while a Common Sensing TDG probe was utilized in 2003 and 2005.

TDG and dissolved oxygen relationships were similar for all study years (Figures 60 and 61). TDG typically exceeded the 110% criterion when the DO criterion (5 mg/L) was achieved in the discharge and DO increase was 4.5 mg/L.

IV. CONCLUSIONS

Significant improvements in discharge DO concentrations were achieved since 2002 and are documented in this study. Various operating scenarios and configurations provided valuable data to help optimize operating conditions in terms of DO concentrations downstream of the Osage Project. The following summary provides the key study findings.

IV.A. General Findings

Several fundamental relationships were observed in all study year datasets when comparing tailwater DO concentration, TDG, airflow, oxygen transfer efficiency, discharge rates, and tailrace elevation. These relationships can be summarized as follows:

- Tailwater DO concentrations generally decreased with increasing turbine discharge rate and tailrace elevation.
- Airflow through the study turbines generally decreased with increasing tailrace elevation.
- Oxygen transfer efficiency increased with increasing discharge rate and increasing tailrace elevation.
- The relationship between aeration efficiency (which accounts for water temperature) and air:discharge ratio was similar for all study year datasets, providing further validation that aeration is a function of the air:discharge ratio.
- The relationship between TDG saturation and air:discharge ratio is similar to aeration efficiency. TDG saturation is also directly related to DO saturation.
- The TDG water quality criterion (110% saturation) was typically exceeded when the DO criterion (5 mg/L minimum) was exceeded.

The study data also allow comparison of various turbine designs and venting configurations. These comparisons provide valuable insight into potential Project modifications for improvement of downstream water quality. The following conclusions are presented based on the study data:

IV.B. Main Generator 6

- Use of draft tubes and main vents together resulted in consistently higher air flows than use of draft tube vent or new main vents alone.
- The four new main vents were more effective than the draft tube vent at lower gate settings through the range of tailrace elevations.
- The four new main vents in 2005 had similar performance to the two original main vents in the 2002 and 2003 when tailrace elevations were 560 or greater.
- The draft tube vent provided greater airflow than the main vents at the higher gate settings through the range of tailrace elevations.

- The combination of the new main vents and the draft tube vents produced the greatest amount of total airflow for all MG6 configurations of gate settings and tailrace elevations
- The relationship between DO and discharge at high tailrace elevations were opposite for the new main vents and the draft tube vent only. The new main vent configuration resulted in higher DO levels at the lower gate settings, while the draft tube vent produced higher DO levels as discharge increased.
- The draft tube vent and the four new main vents installed at MG6 in 2005 increased airflow compared to 2002 and 2003 studies of original main and manual auxiliary vents. MG6 discharge DO concentrations were on average 1.2 to 2.4 mg/L higher in 2005 than in 2002 at moderate to high tailrace elevations.
- With the draft tube and main vents open, the MG6 discharge met or exceeded the dissolved oxygen water quality criterion (5 mg/L) until a relatively high tailrace elevation (560') was reached.
- Discharge DO was enhanced by modifications made to MG6 from 2002 to 2005 as summarized in Table 4.

**Table 4: Main Generator 6 Discharge Dissolved Oxygen Enhancement
from 2002 to 2005**

Tailrace Elevation (ft. MSL)	Discharge Dissolved Oxygen (mg/L)								
	2002			2005			Difference (2005-2002)		
	Gate Setting			Gate Setting			Gate Setting		
	40%	60%	80% & 90%	40%	60%	85%	40%	60%	85%
556	3.90	3.11	2.04	5.59	5.73	5.05	1.69	2.62	3.02
560	3.01	3.05	2.00	4.95	5.17	3.70	1.94	2.12	1.71
563	3.61	3.28	2.60	4.50	4.84	3.84	0.89	1.56	1.25

IV.C. Main Generator 3

- Removal of check valves from the MG3 vents in 2005 had no significant impacts on airflow through the units.
- Airflows through two main vents were similar to those measured in four main vents indicating that there is little gain in airflow with the use of four main vents compared to two.
- Airflows were reduced with one main vent at low gate settings and moderate tailrace elevation, which indicates promise in controlling airflow low tailrace elevations and gate settings. This control measure may be useful in reducing TDG levels during vented, baseflow conditions.
- The fully vented MG3 discharge during 2005 met the 5.0 mg/L dissolved oxygen criterion until high gate setting (85%) and moderate tailrace elevation (556') was reached.
- MG3 discharge DO concentrations increased an average of 1.2 to 1.6 mg/L in 2005 compared to 2002 at moderate to high tailrace elevations (Table 5). The majority of this increase was observed after the 2002 study year and is attributed to the removal of the nosecone bottom plate.

**Table 5: Main Generator 3 Discharge Dissolved Oxygen Enhancement
from 2002 to 2005**

Tailrace Elevation (ft. MSL)	Discharge Dissolved Oxygen (mg/L)								
	2002			2005			Difference (2005-2002)		
	Gate Setting			Gate Setting			Gate Setting		
	40%	60%	80% & 90%	40%	60%	85%	40%	60%	85%
556	5.02	4.10	3.12	5.95	5.50	4.69	0.93	1.40	1.57
560	3.63	3.21	2.60	4.66	4.82	4.82	1.03	1.61	2.22
563	3.49	3.39	2.92	4.20	4.57	4.47	0.71	1.18	1.56

IV.D. Comparison of Main Generators 3 and 6

- MG6 with draft tube and main vents produced greater airflow and tailrace DO than MG3 at high gate settings (85 %) and moderate to high tailrace elevations (560 to 563).
- MG3 discharge DO at high tailrace and high gate settings was significantly greater than MG6 discharge DO at similar configurations (Table 6)

Table 6: Main Generators 3 and 6 Discharge Dissolved Oxygen Comparison - 2005

Tailrace Elevation (ft. MSL)	Discharge Dissolved Oxygen (mg/L)								
	MG3			MG6			Difference		
	Gate Setting			Gate Setting			Gate Setting		
	40%	60%	85%	40%	60%	85%	40%	60%	85%
556	5.95	5.5	4.69	5.59	5.73	5.05	0.36	-0.23	-0.36
560	4.66	4.82	4.82	4.95	5.17	3.70	-0.29	-0.35	1.12
563	4.2	4.57	4.47	4.50	4.84	3.84	-0.30	-0.27	0.63

*** Negative values indicated that MG6 DO was greater than MG3.

APPENDIX 1

Figure 1: Modifications made to Main Generator 6 2003 and 2005

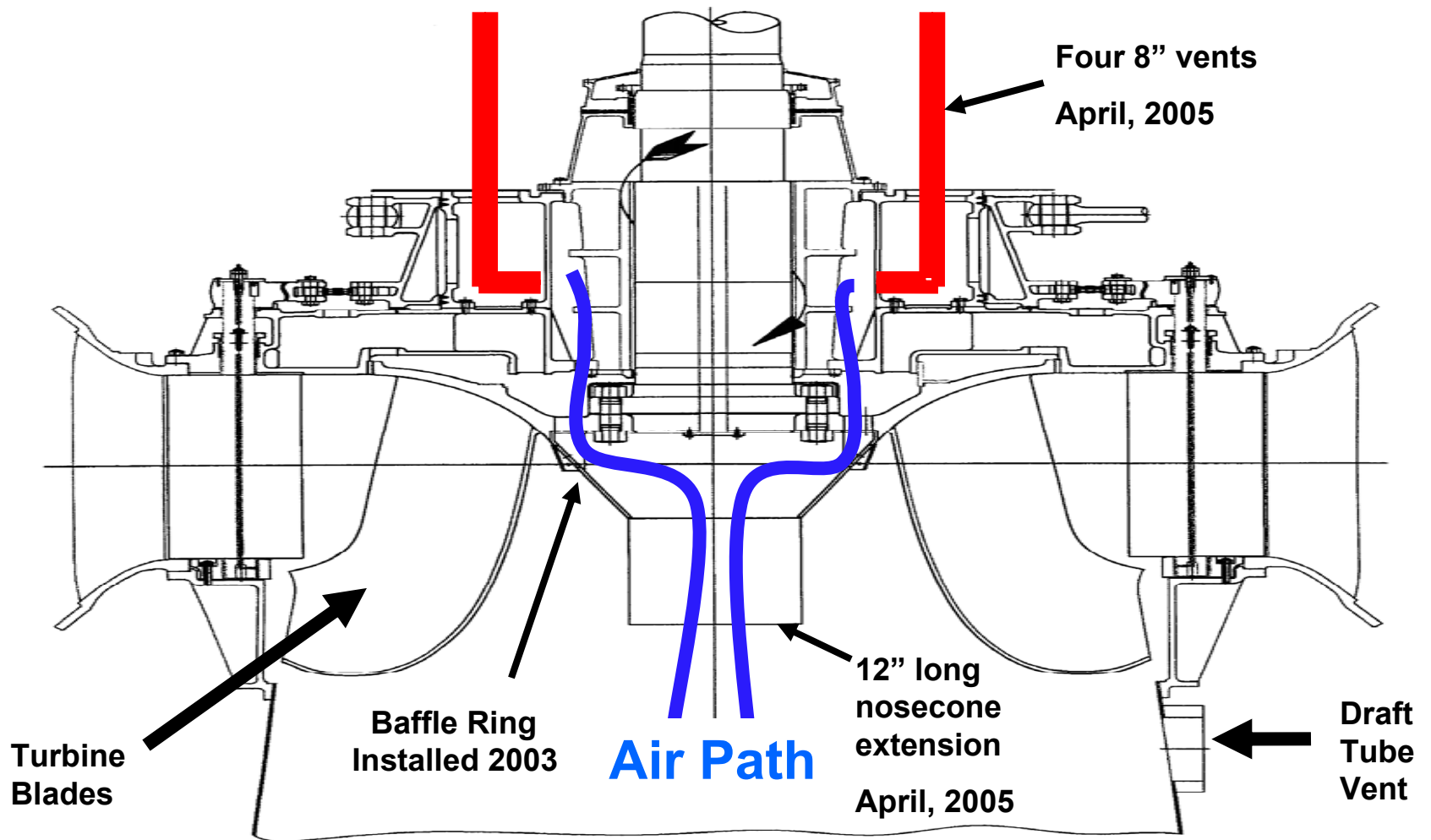


Figure 2
Diagram of Discrete Sampling Device

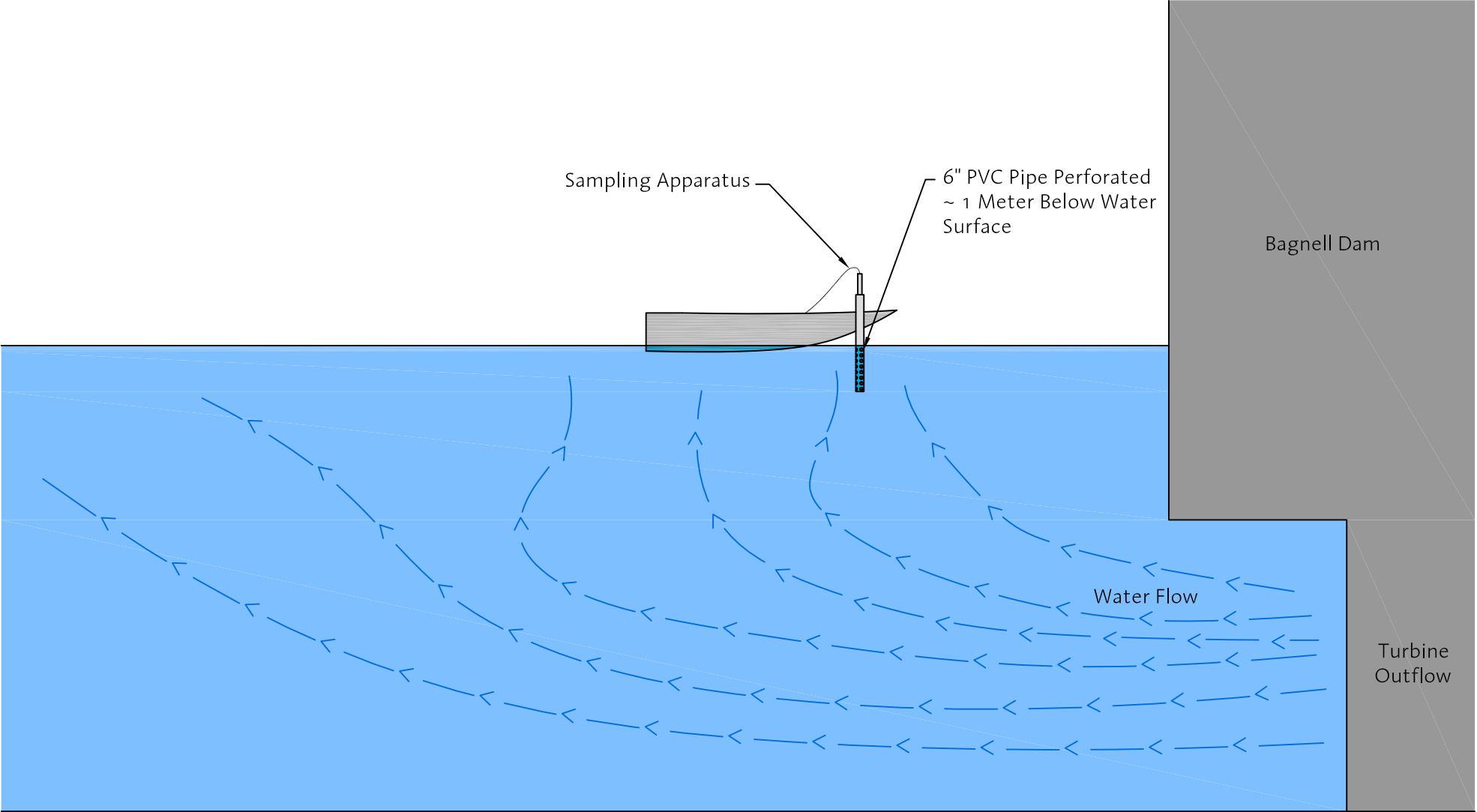


Figure 3
Photograph of Discrete Sampling Device

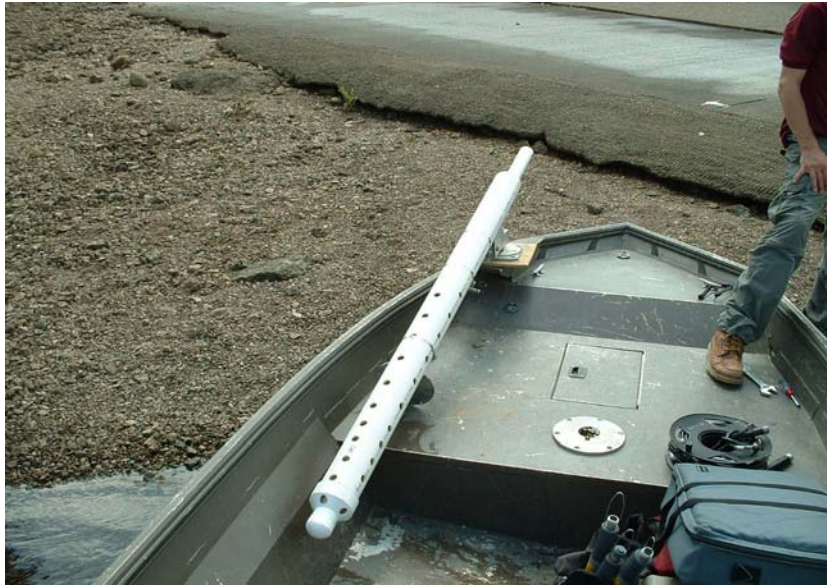
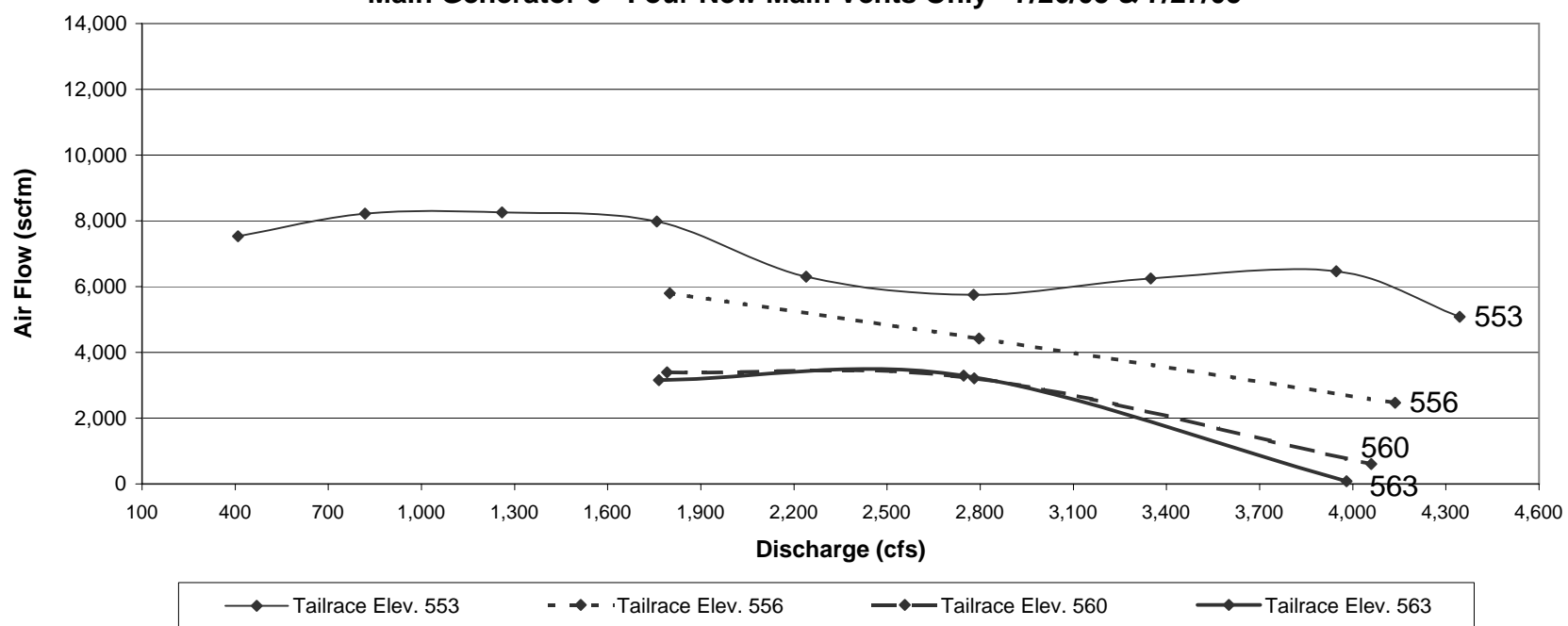


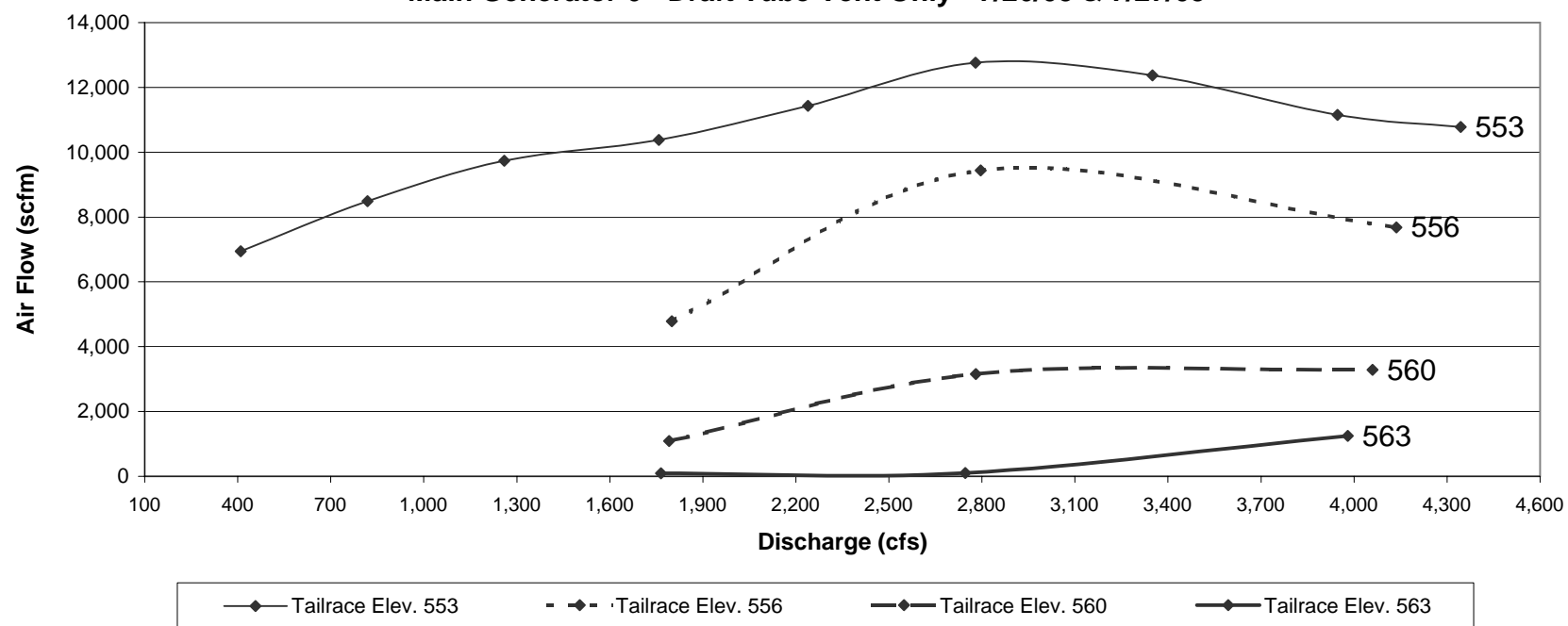
Figure 4
Photograph of Discrete Sampling Device - Deployed



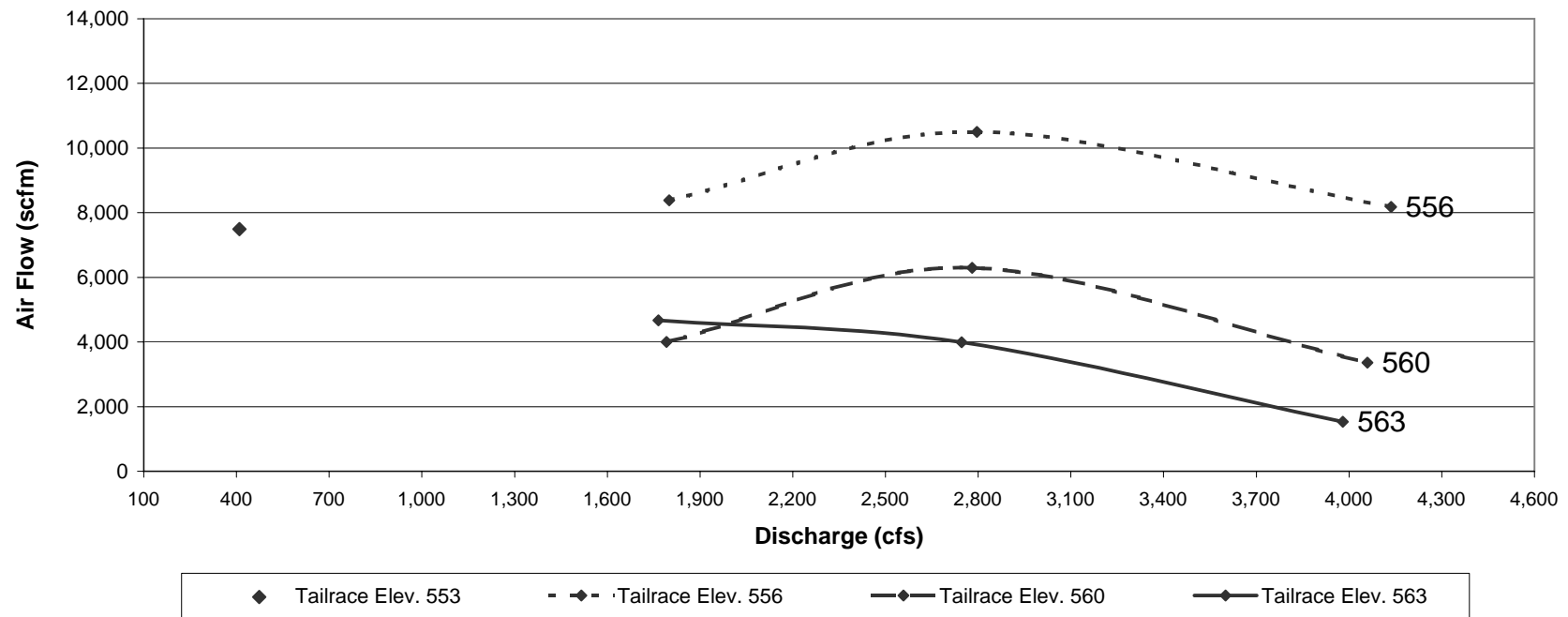
**Figure 5: Relationship between Standard Air Flow and Discharge -
Main Generator 6 - Four New Main Vents Only - 7/26/05 & 7/27/05**



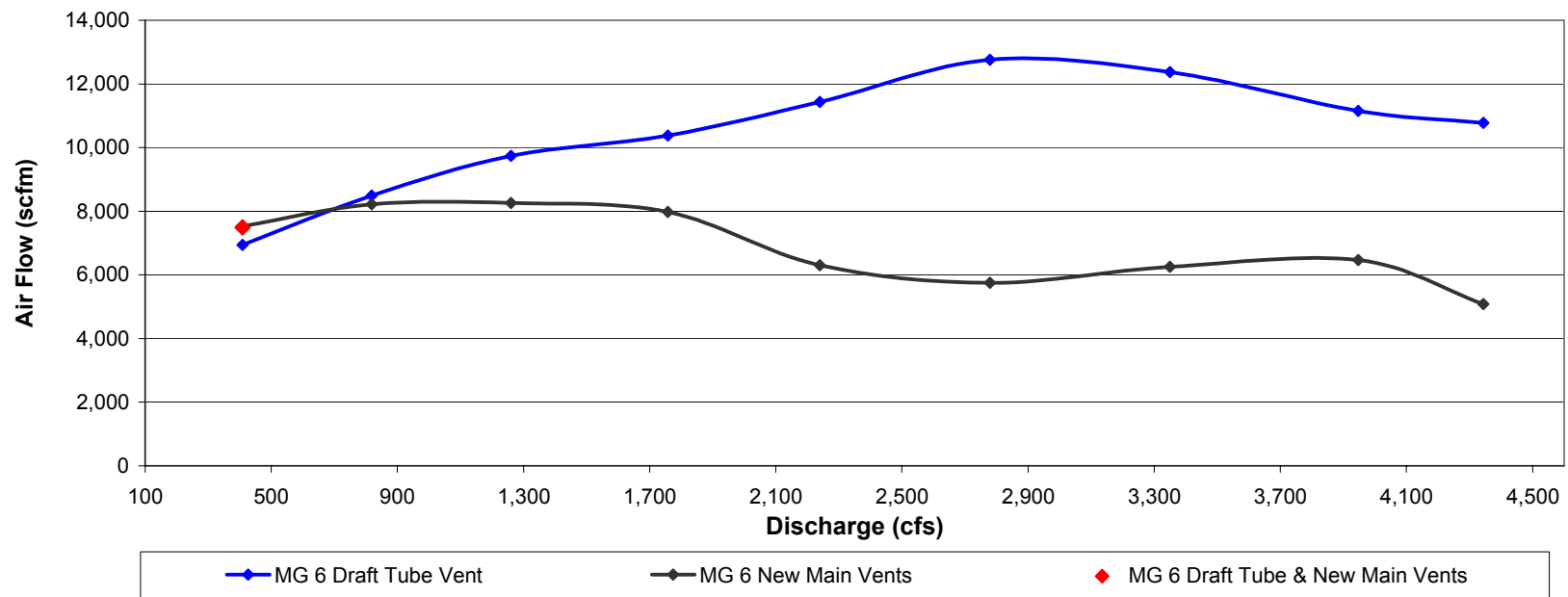
**Figure 6: Relationship between Standard Air Flow and Discharge -
Main Generator 6 - Draft Tube Vent Only - 7/26/05 & 7/27/05**



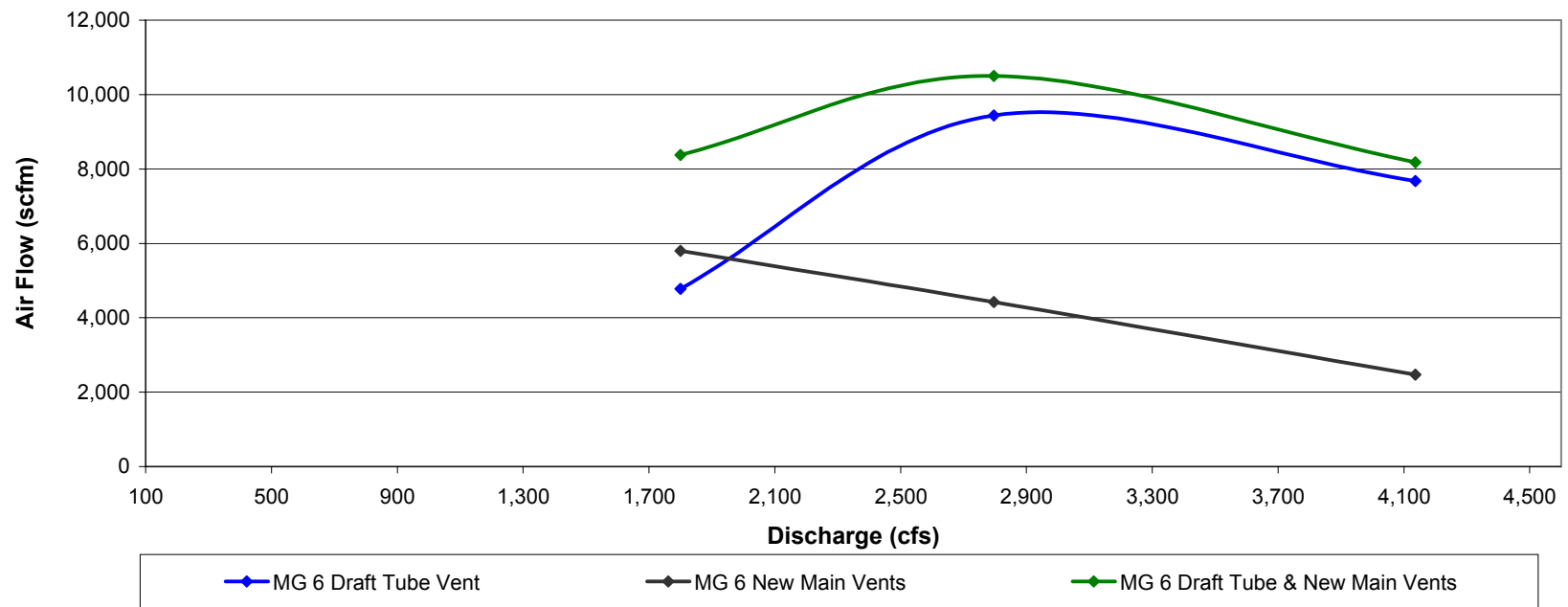
**Figure 7: Relationship between Standard Air Flow and Discharge -
Main Generator 6 - Draft Tube and Four New Main Vents - 7/26/05 & 7/27/05**



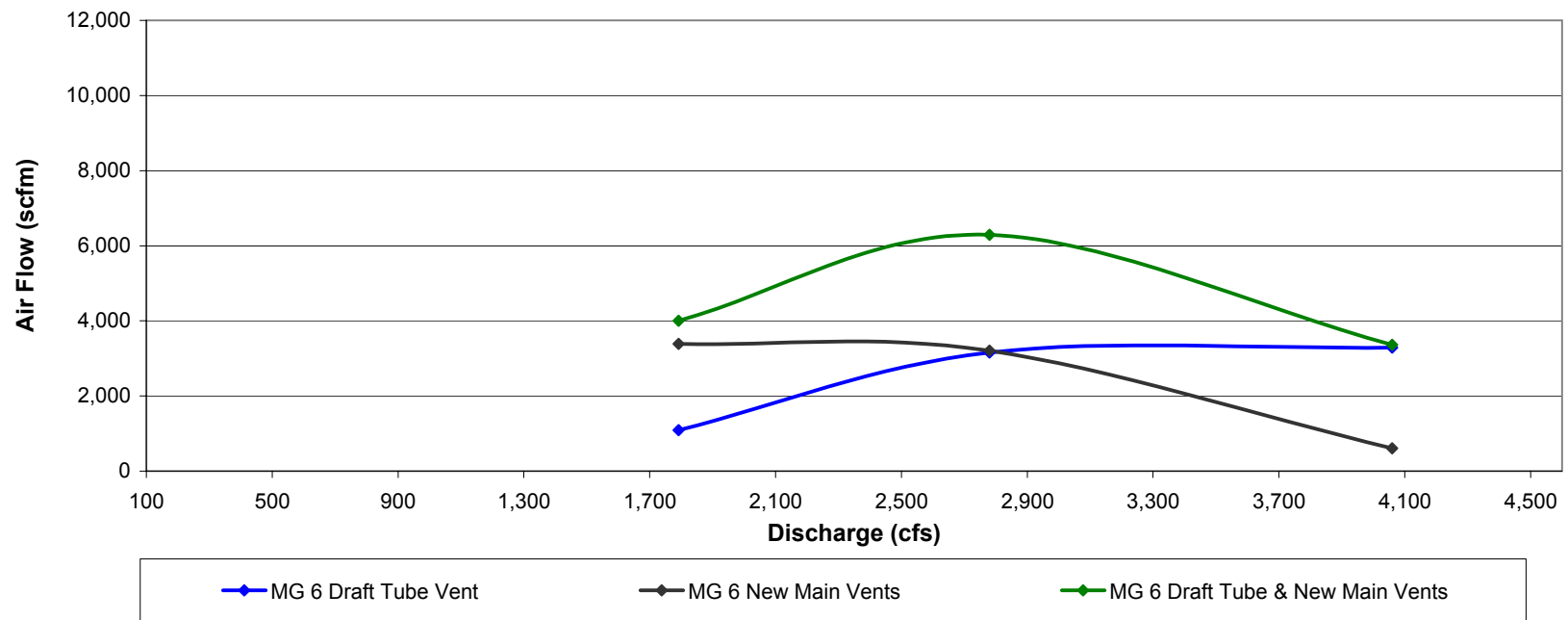
**Figure 8: Relationship between Standard Air Flow and Discharge -
Tailrace Elevations 553 - 2005 Main Generator 6**



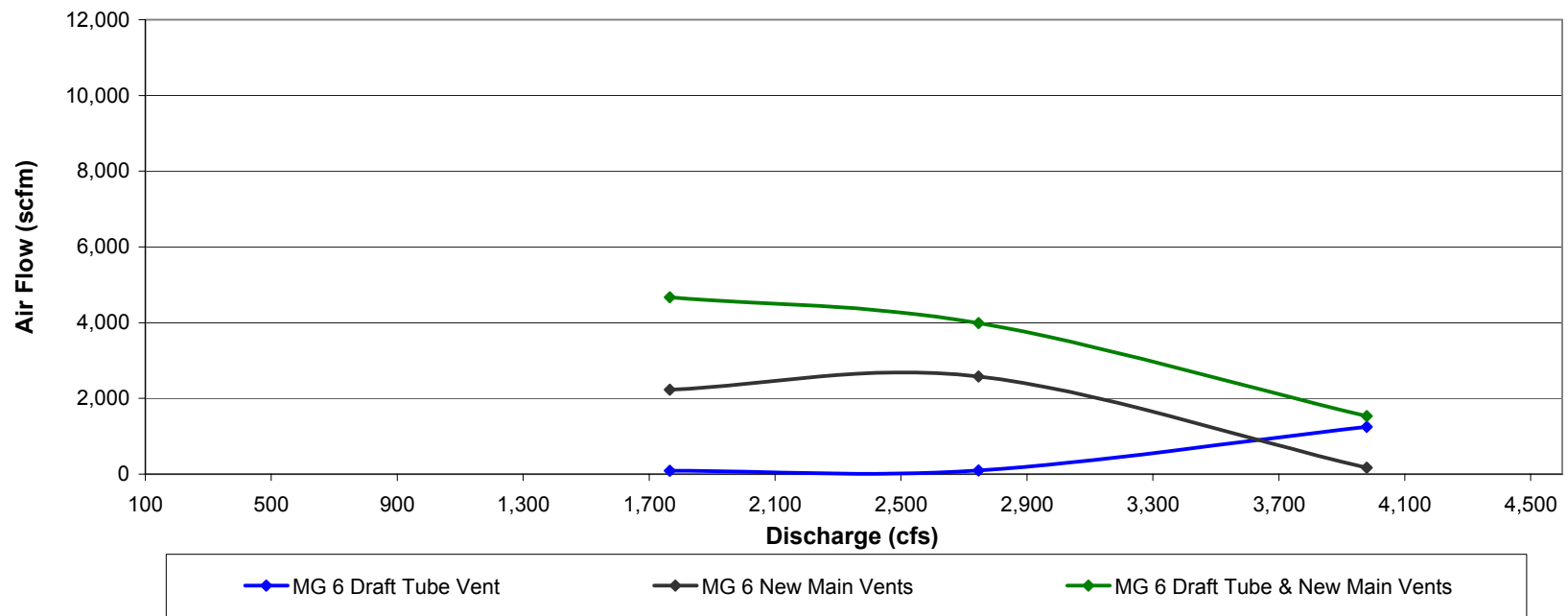
**Figure 9: Relationship between Standard Air Flow and Discharge -
Tailrace Elevation 556 - 2005 Main Generator 6**



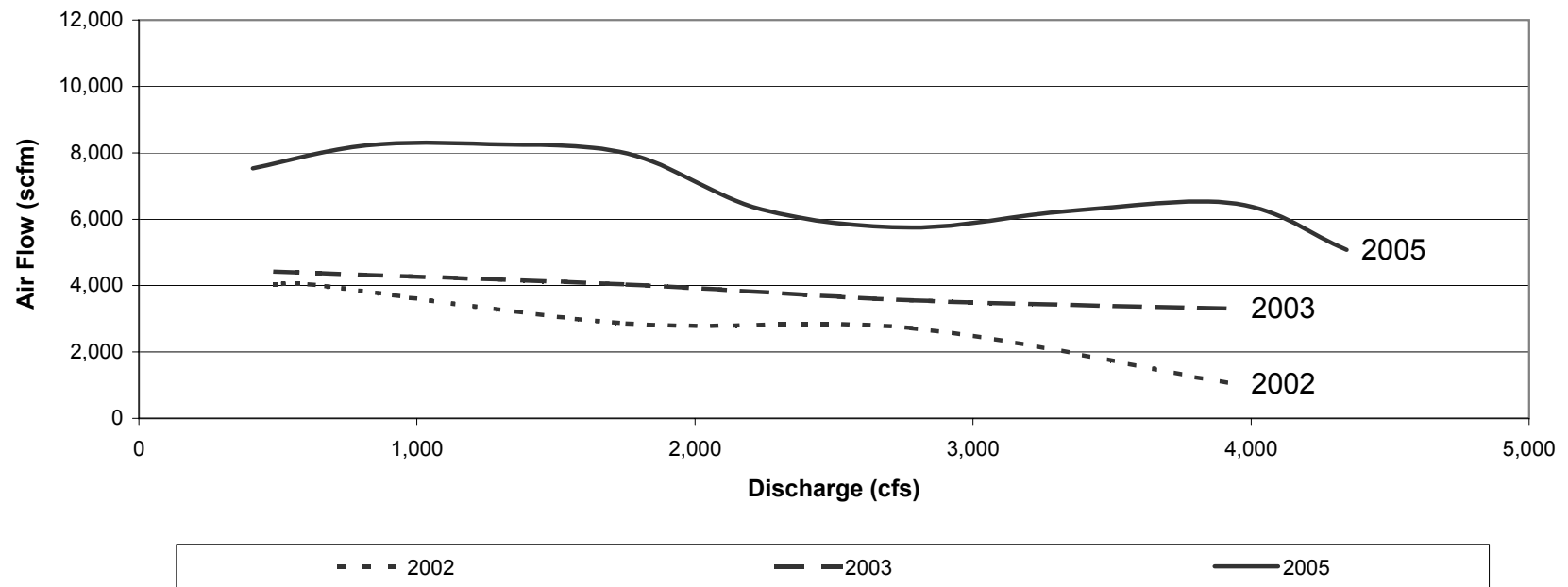
**Figure 10: Relationship between Standard Air Flow and Discharge -
Tailrace Elevation 560 - 2005 Main Generator 6**



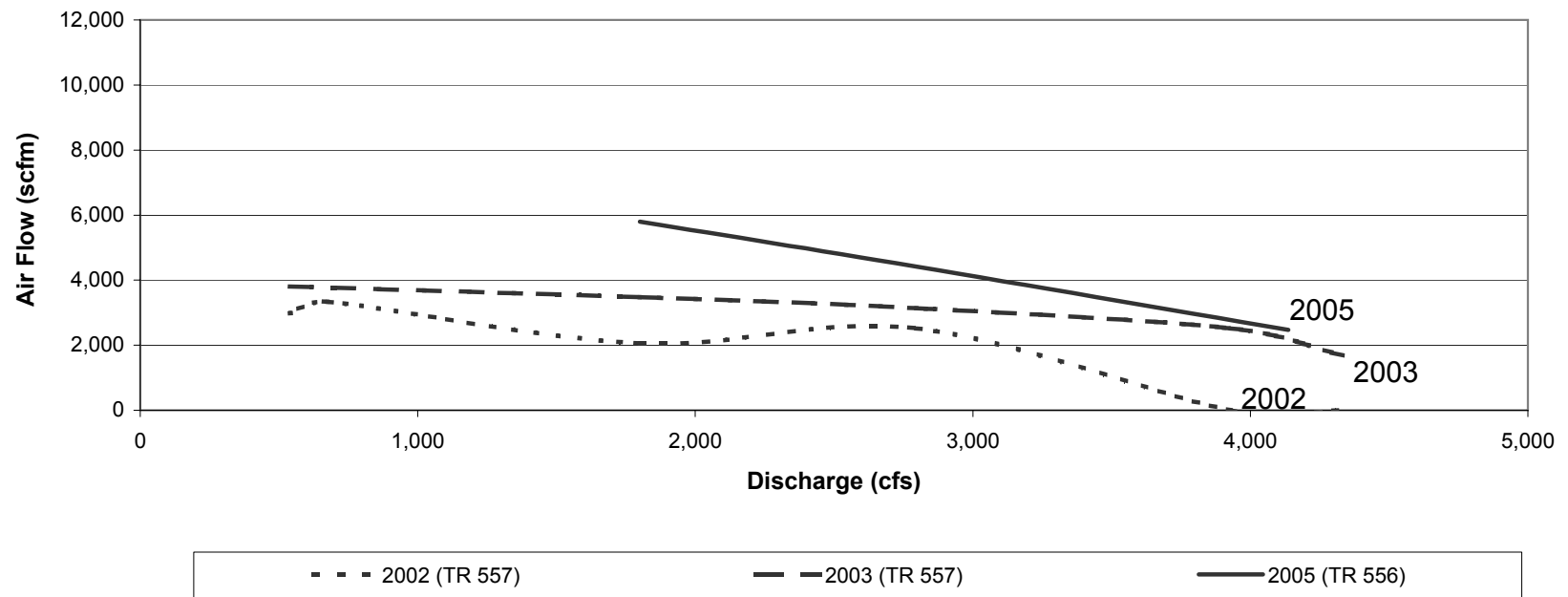
**Figure 11: Relationship between Standard Air Flow and Discharge -
Tailrace Elevation 563 - 2005 Main Generator 6**



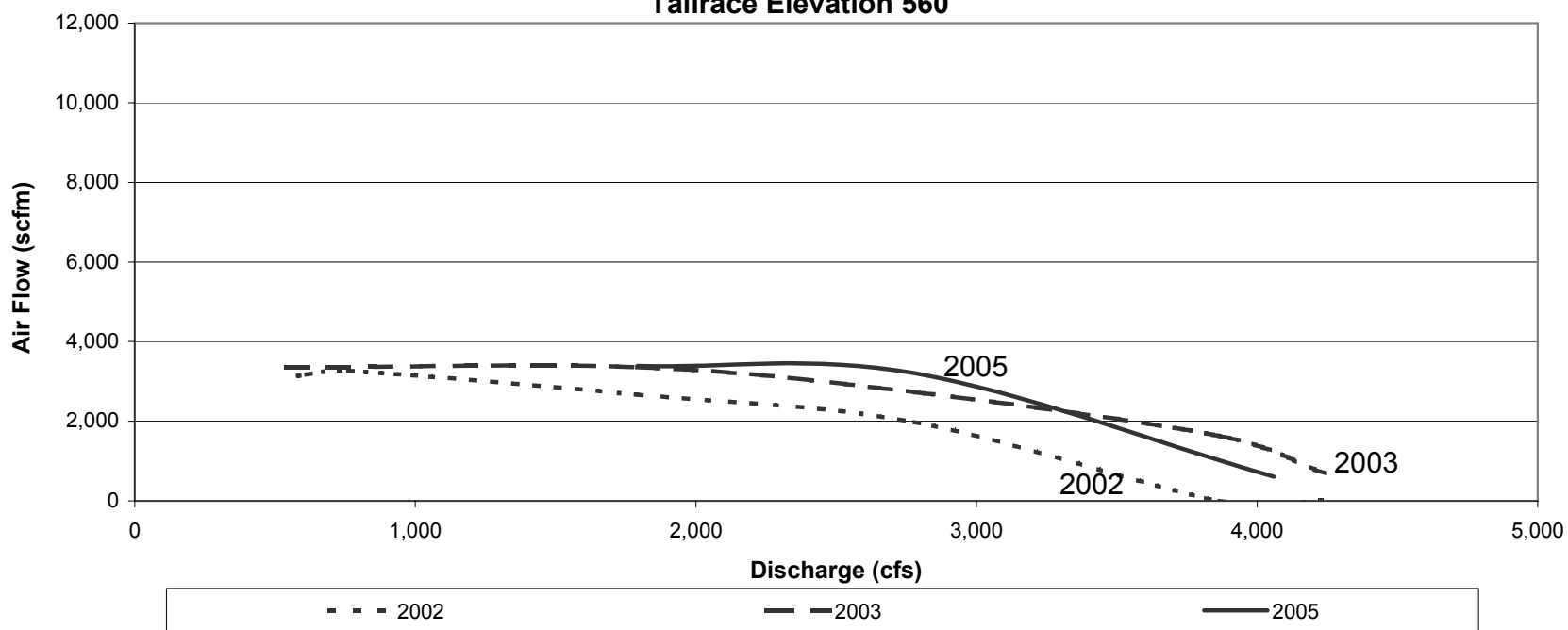
**Figure 12: Relationship between Standard Air Flow and Discharge -
Main Generator 6 - 2002 & 2003 - Two Original Main Vents & 2005 - Four New Main Vents
Tailrace Elevation 554**



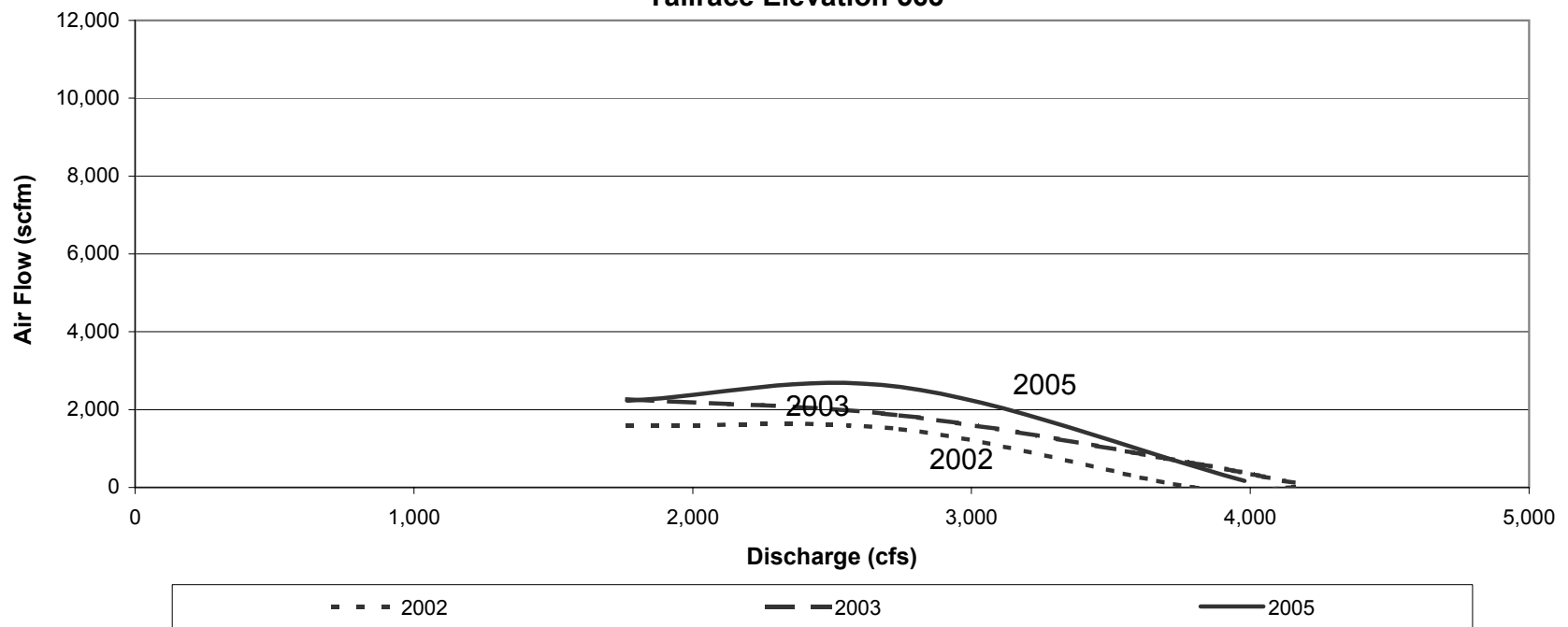
**Figure 13: Relationship between Standard Air Flow and Discharge -
Main Generator 6 - 2002 & 2003 - Two Original Main Vents & 2005 - Four New Main Vents
Tailrace Elevation 557 and 556**



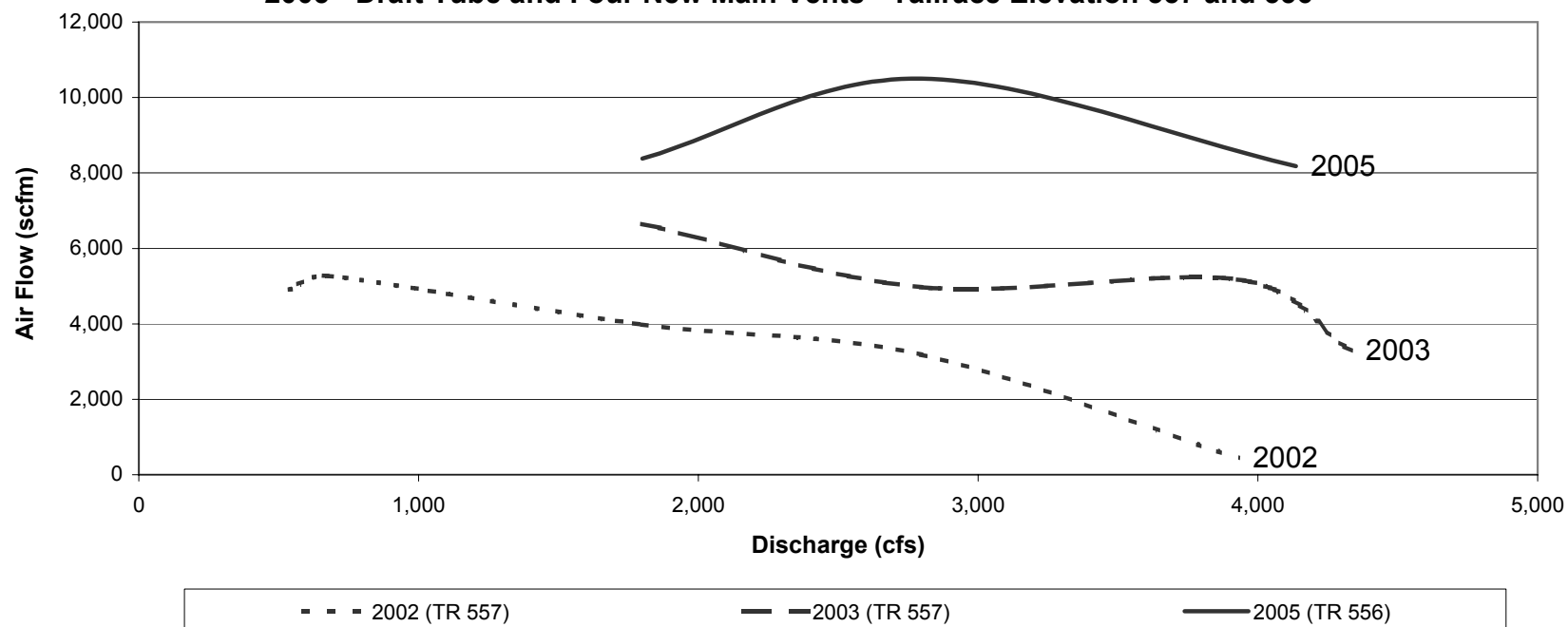
**Figure 14: Relationship between Standard Air Flow and Discharge -
Main Generator 6 - 2002 & 2003 - Two Original Main Vents & 2005 - Four New Main Vents
Tailrace Elevation 560**



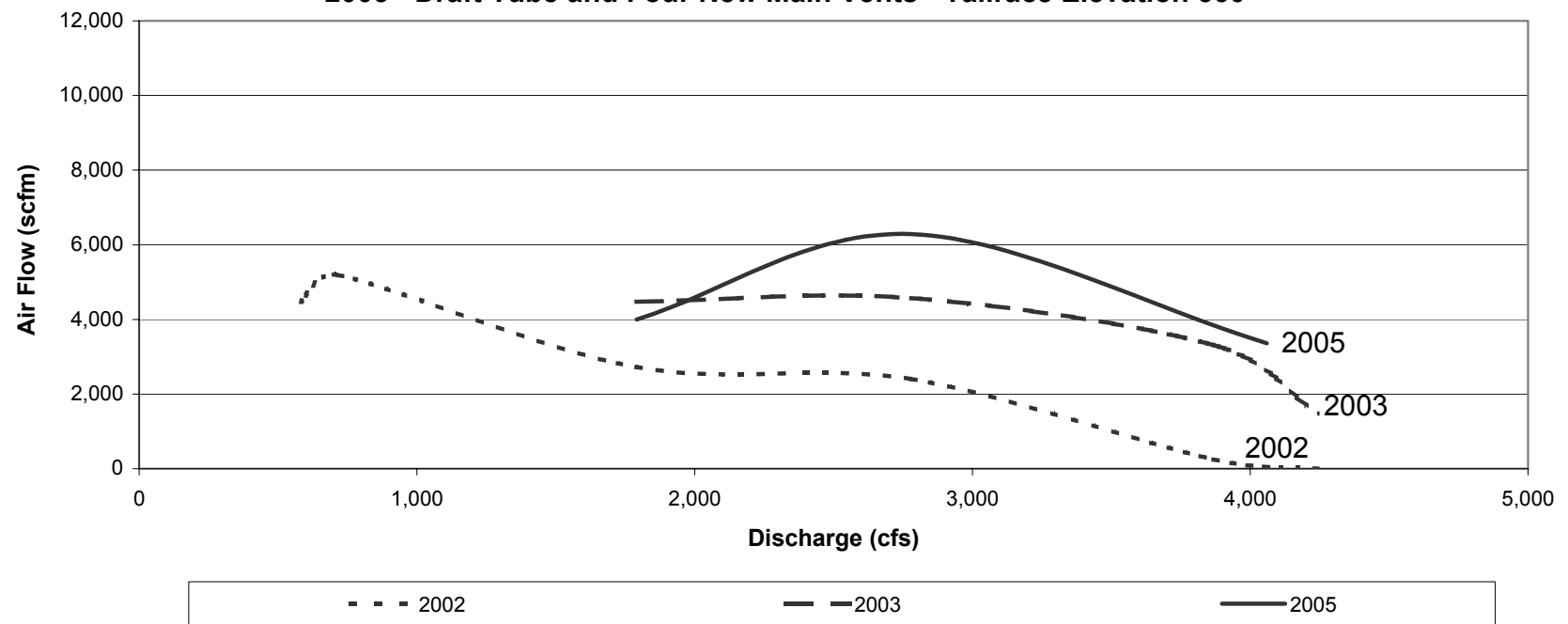
**Figure 15: Relationship between Standard Air Flow and Discharge -
Main Generator 6 - 2002 & 2003 - Two Original Main Vents & 2005 - Four New Main Vents
Tailrace Elevation 563**



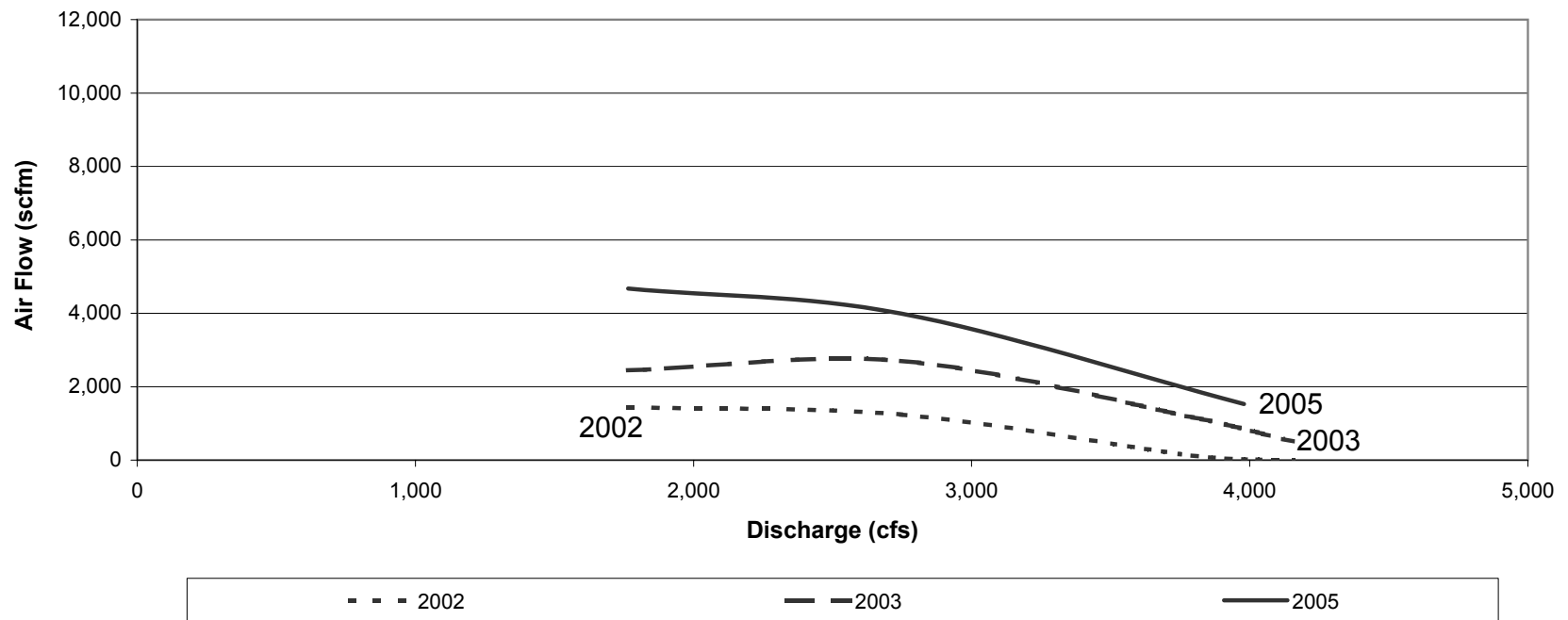
**Figure 16: Relationship between Standard Airflow and Discharge -
Main Generator 6 - 2002 & 2003 - Auxiliary Vents and Two Original Main Vents &
2005 - Draft Tube and Four New Main Vents - Tailrace Elevation 557 and 556**



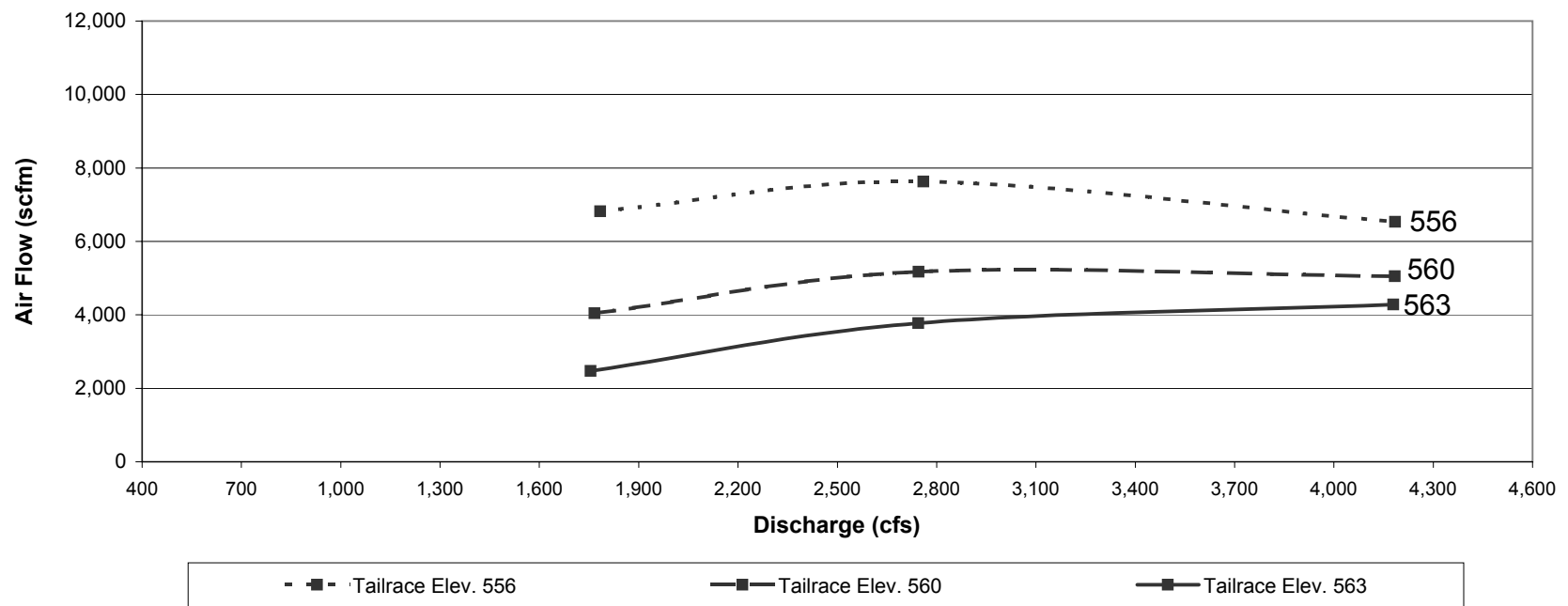
**Figure 17: Relationship between Standard Airflow and Discharge -
Main Generator 6 - 2002 & 2003 - Auxiliary Vents and Two Original Main Vents &
2005 - Draft Tube and Four New Main Vents - Tailrace Elevation 560**



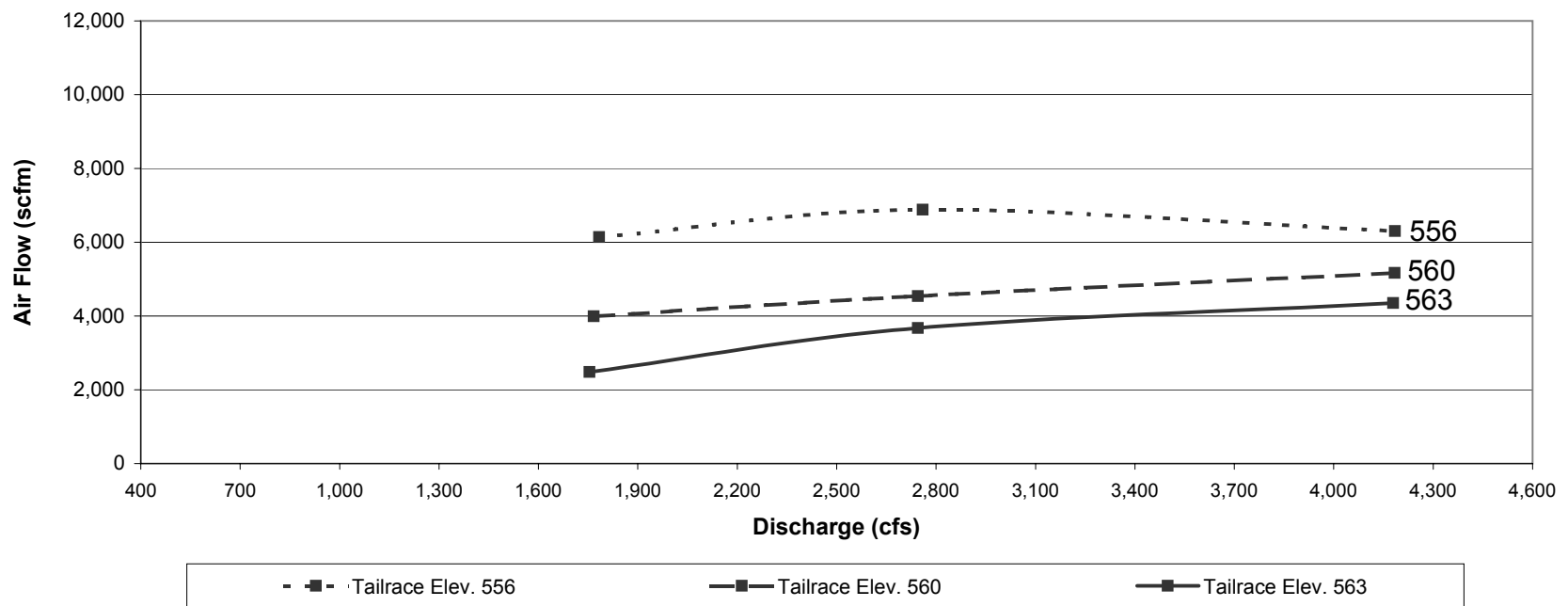
**Figure 18: Relationship between Standard Airflow and Discharge -
Main Generator 6 - 2002 & 2003 - Auxiliary Vents and Two Original Main Vents &
2005 - Draft Tube and Four New Main Vents - Tailrace Elevation 563**



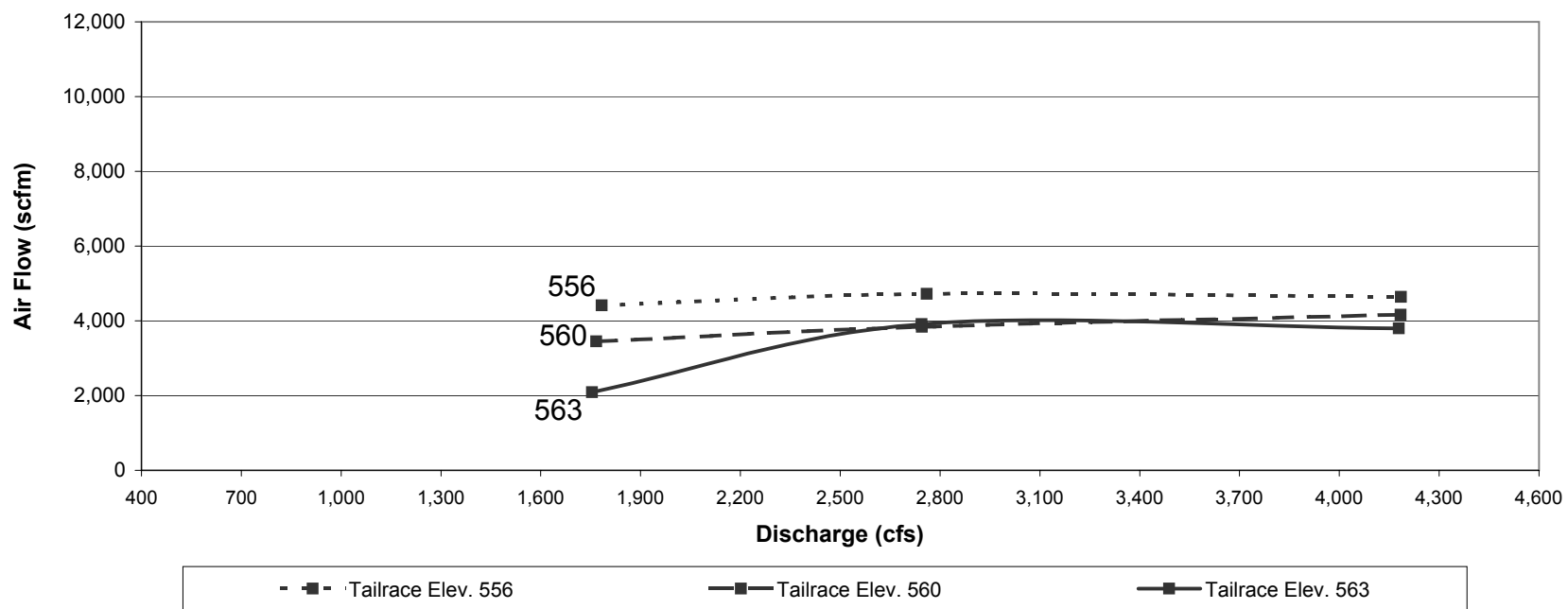
**Figure 19: Relationship between Standard Air Flow and Discharge -
Main Generator 3 - Four Main Vents - 7/26/05**



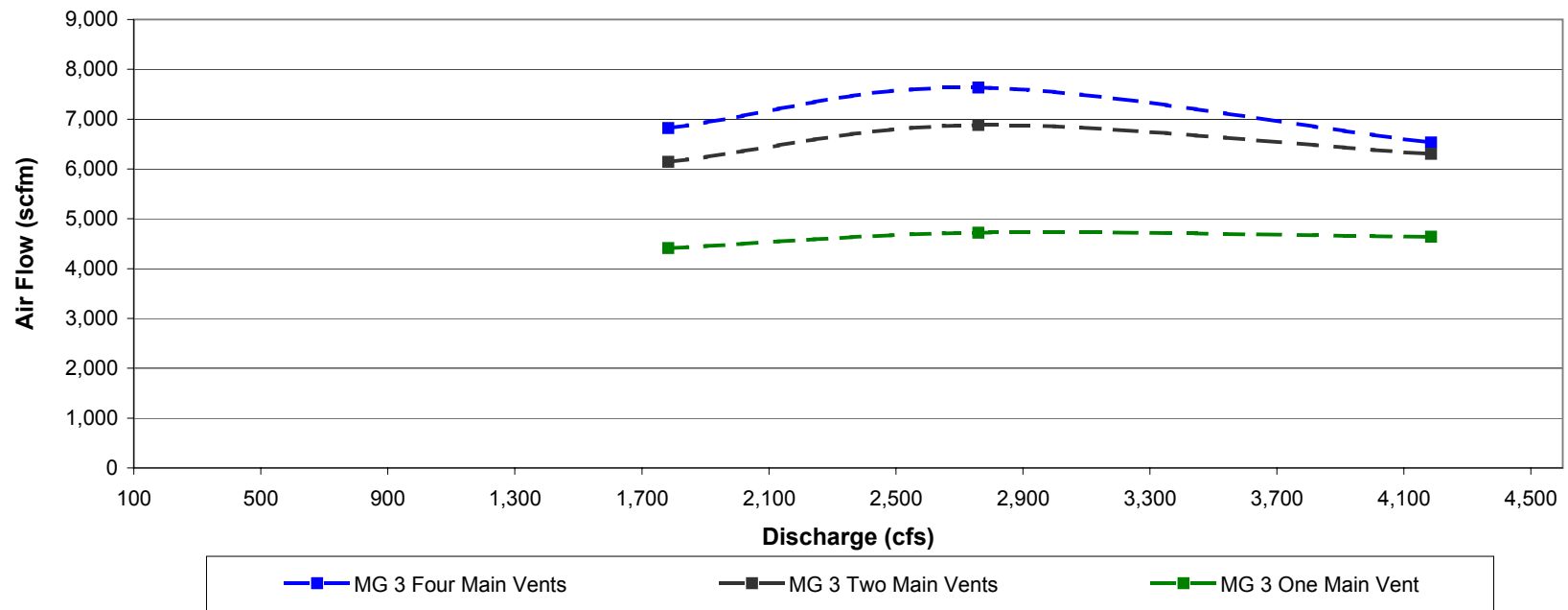
**Figure 20: Relationship between Standard Air Flow and Discharge -
Main Generator 3 - Two Main Vents - 7/26/05**



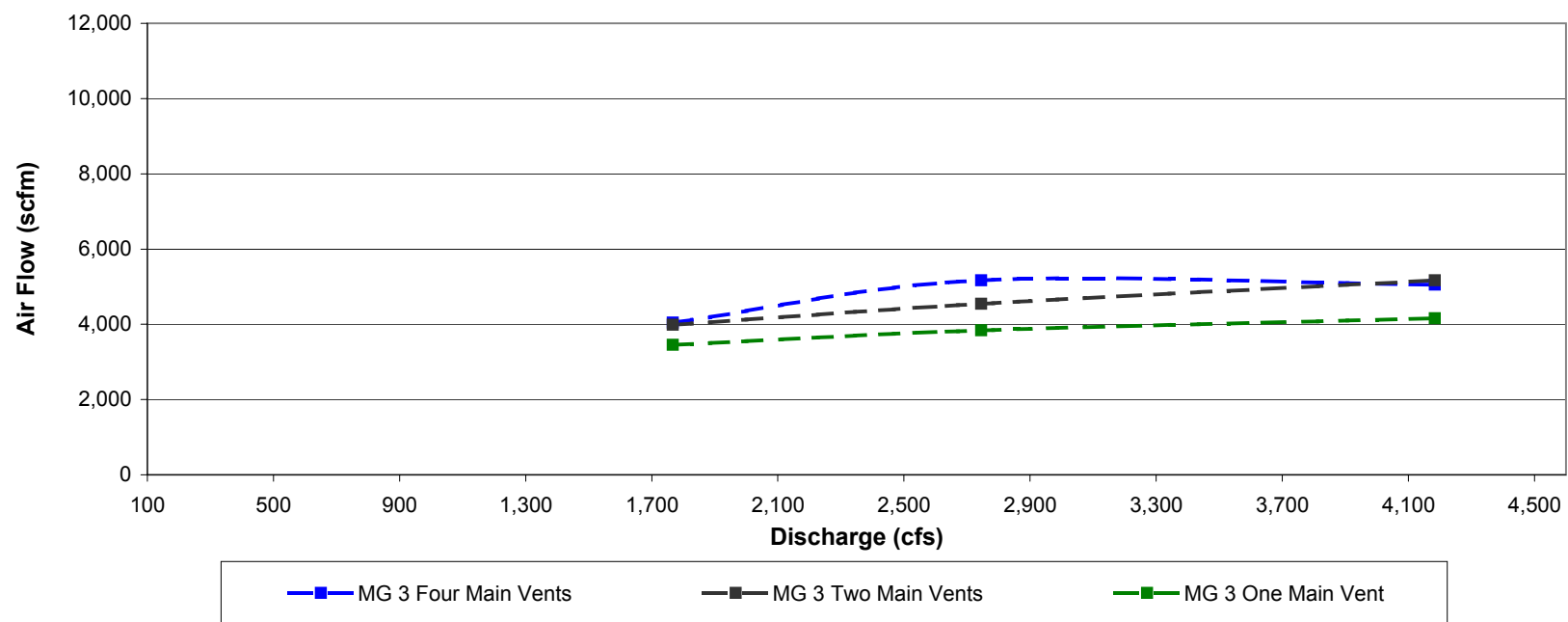
**Figure 21: Relationship between Standard Air Flow and Discharge -
Main Generator 3 - One Main Vent - 7/26/05**



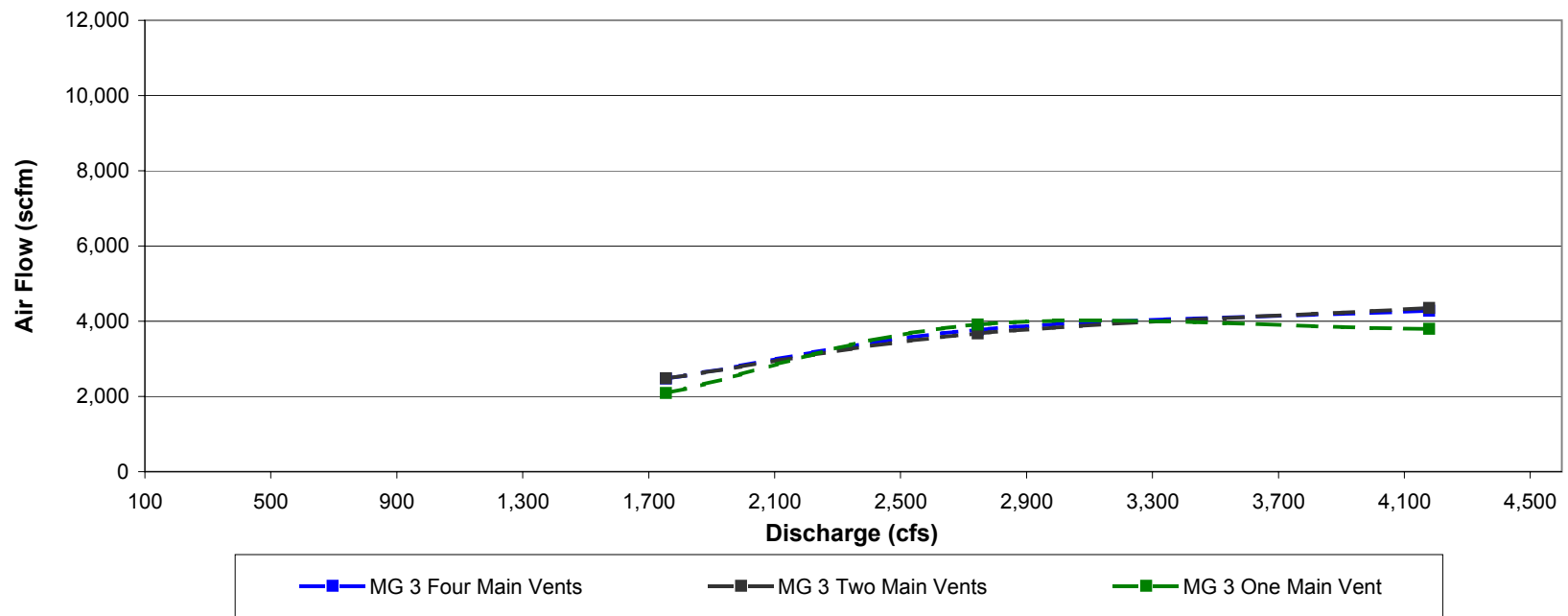
**Figure 22: Relationship between Standard Air Flow and Discharge -
Tailrace Elevation 556 - 2005 Main Generator 3**



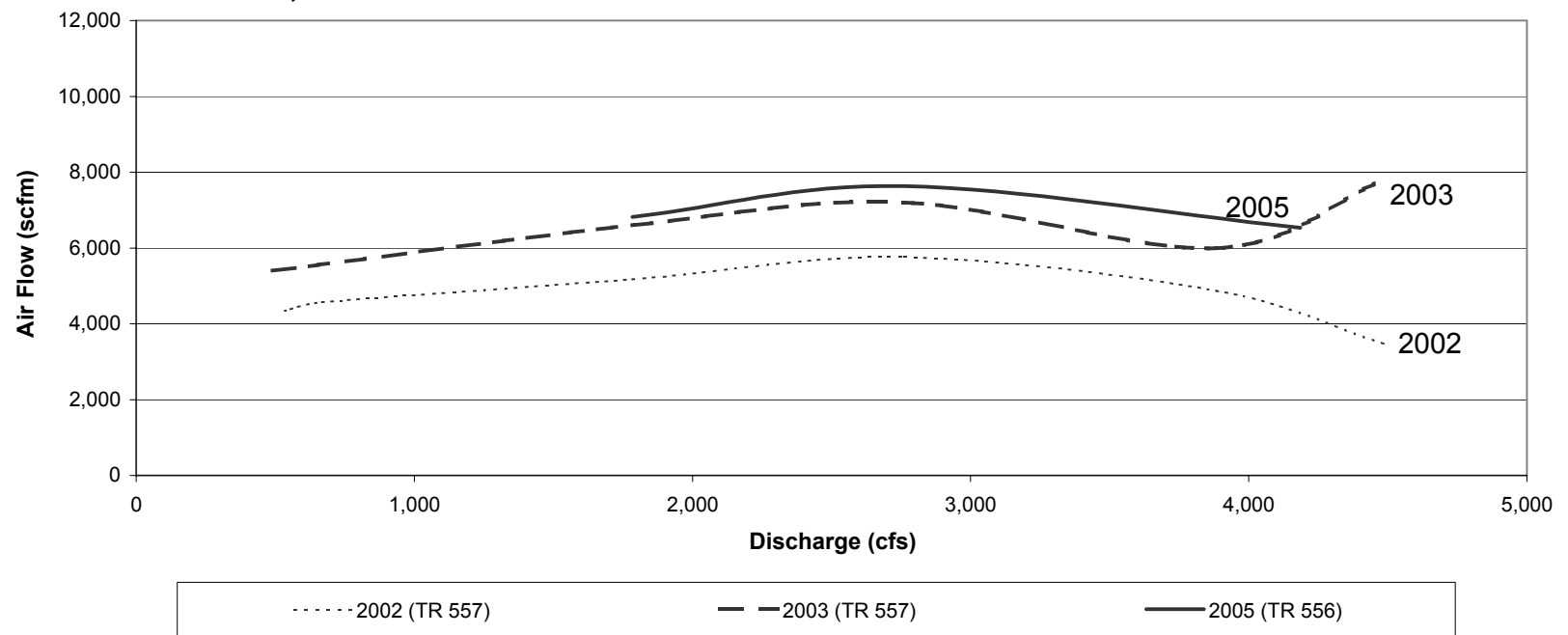
**Figure 23: Relationship between Standard Air Flow and Discharge -
Tailrace Elevation 560 - 2005 Main Generator 3**



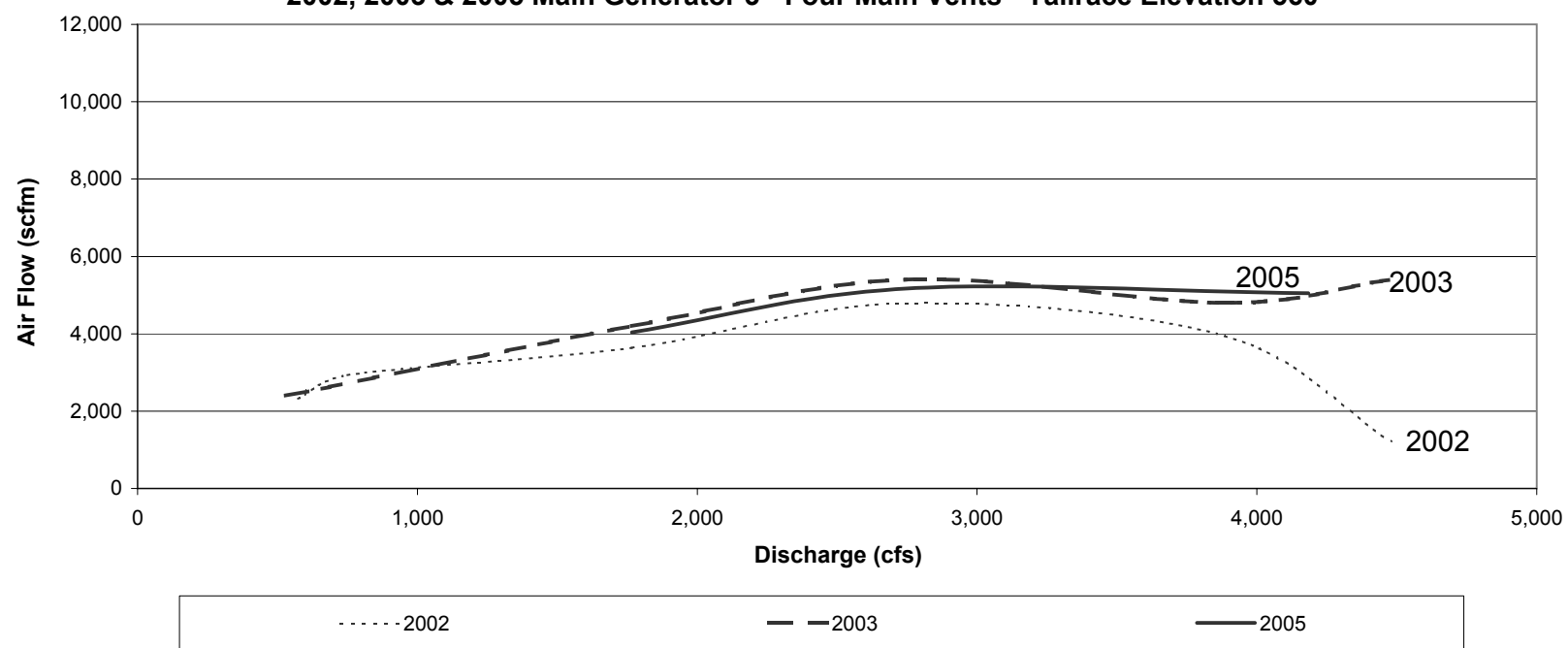
**Figure 24: Relationship between Standard Air Flow and Discharge -
Tailrace Elevation 563 - 2005 Main Generator 3**



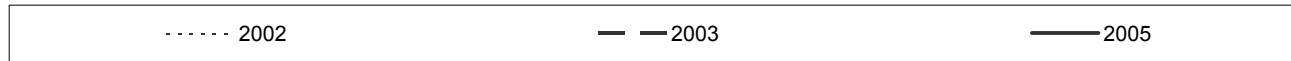
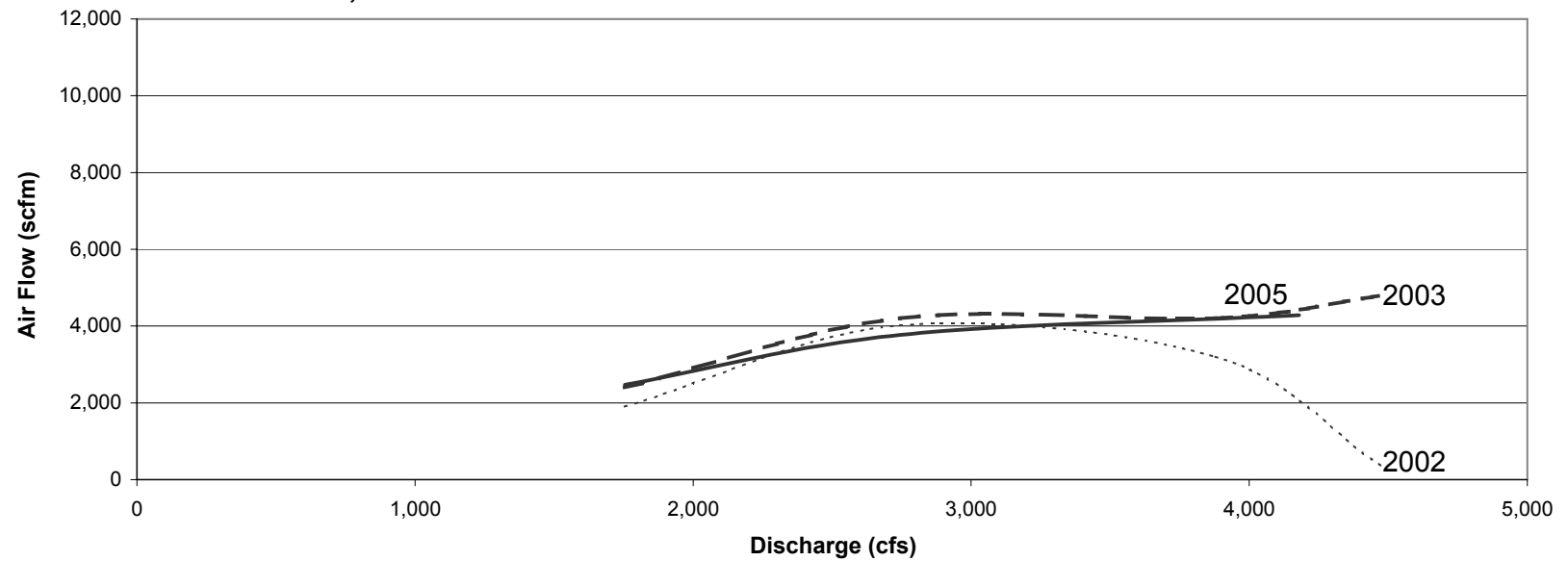
**Figure 25: Relationship between Standard Air Flow and Discharge -
2002, 2003 & 2005 Main Generator 3 - Four Main Vents - Tailrace Elevation 557 and 556**



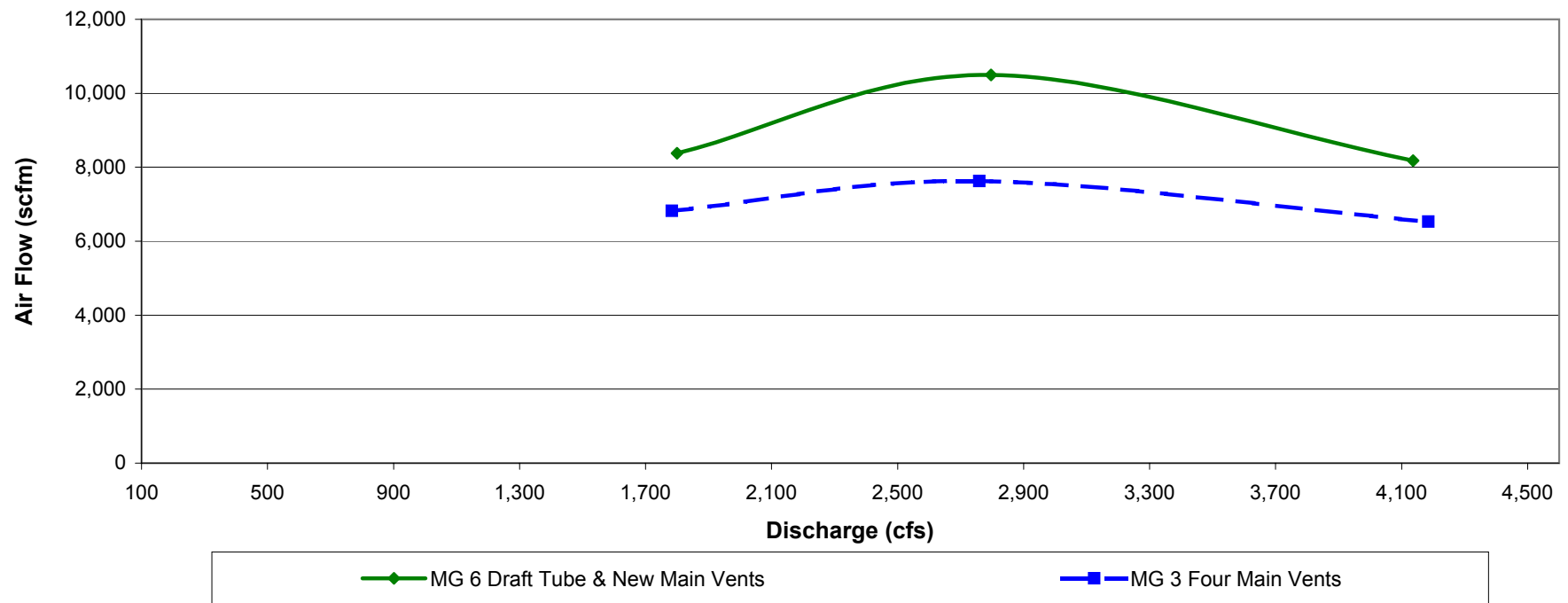
**Figure 26: Relationship between Standard Air Flow and Discharge -
2002, 2003 & 2005 Main Generator 3 - Four Main Vents - Tailrace Elevation 560**



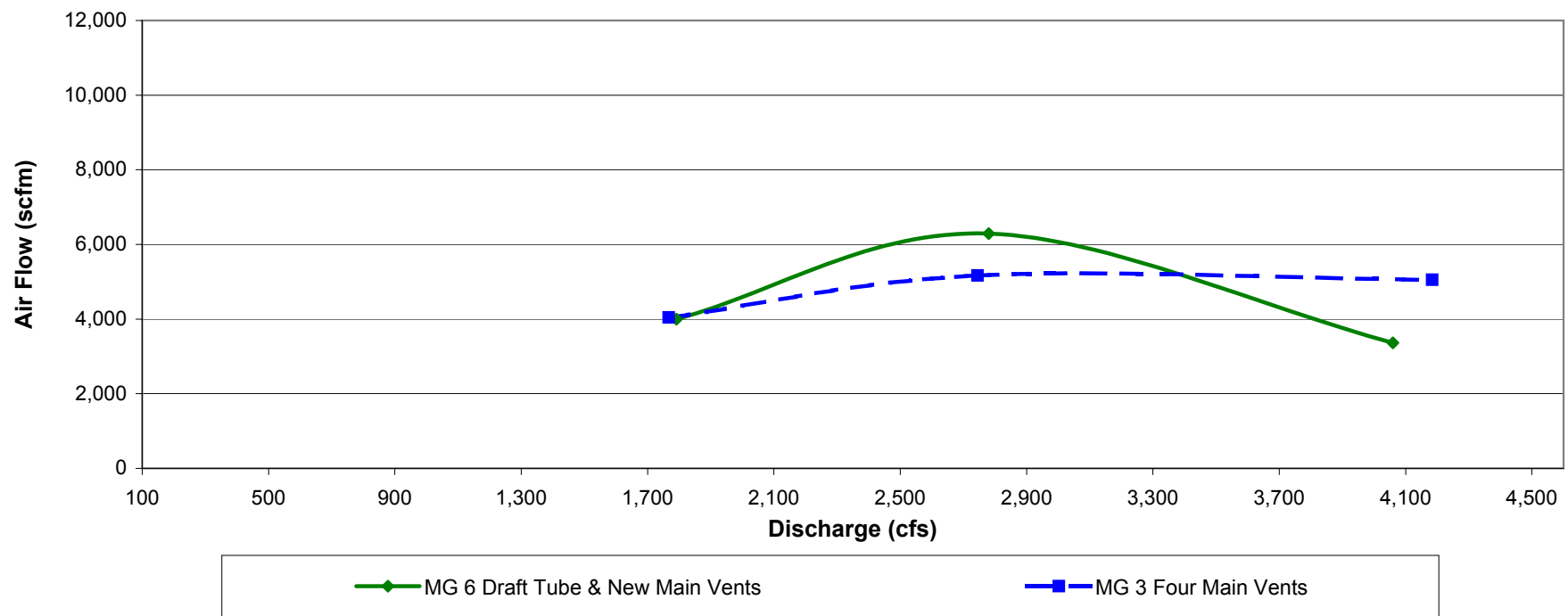
**Figure 27: Relationship between Standard Air Flow and Discharge -
2002, 2003 & 2005 Main Generator 3 - Four Main Vents - Tailrace Elevation 563**



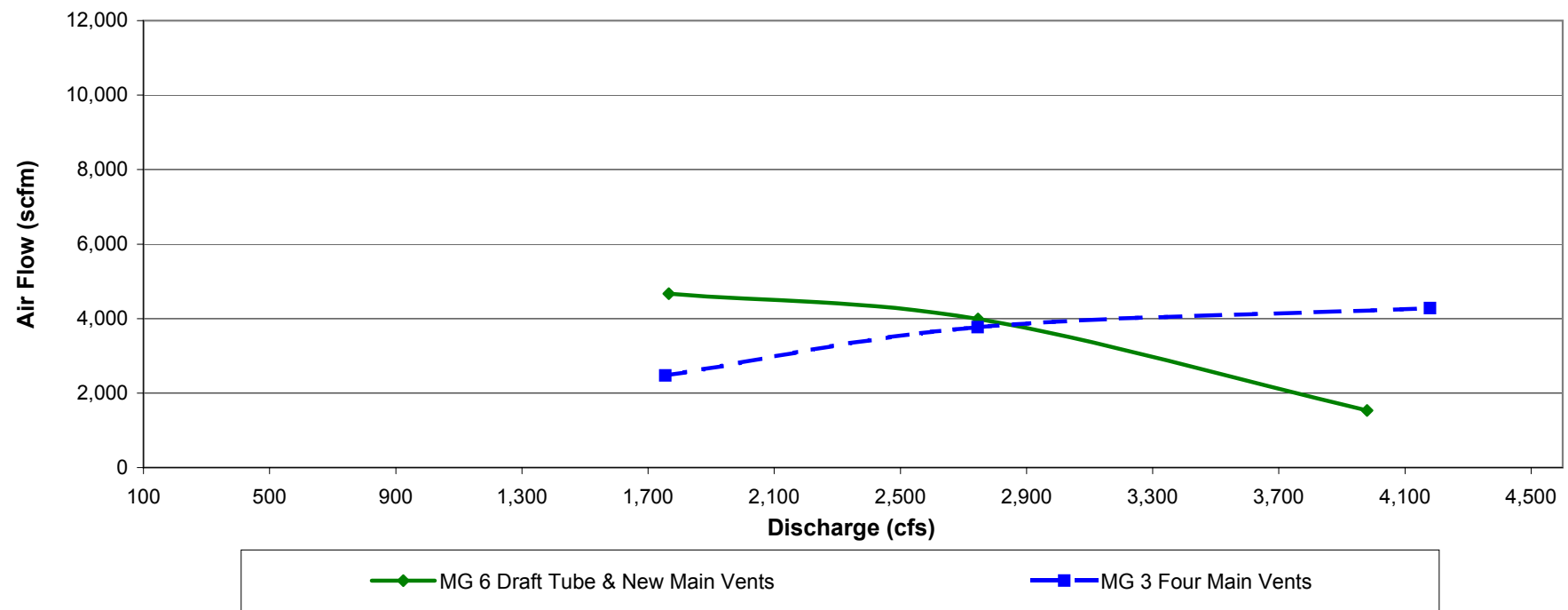
**Figure 28: Relationship between Standard Air Flow and Discharge -
Tailrace Elevation 556 - 2005 Main Generator 3 and 6**



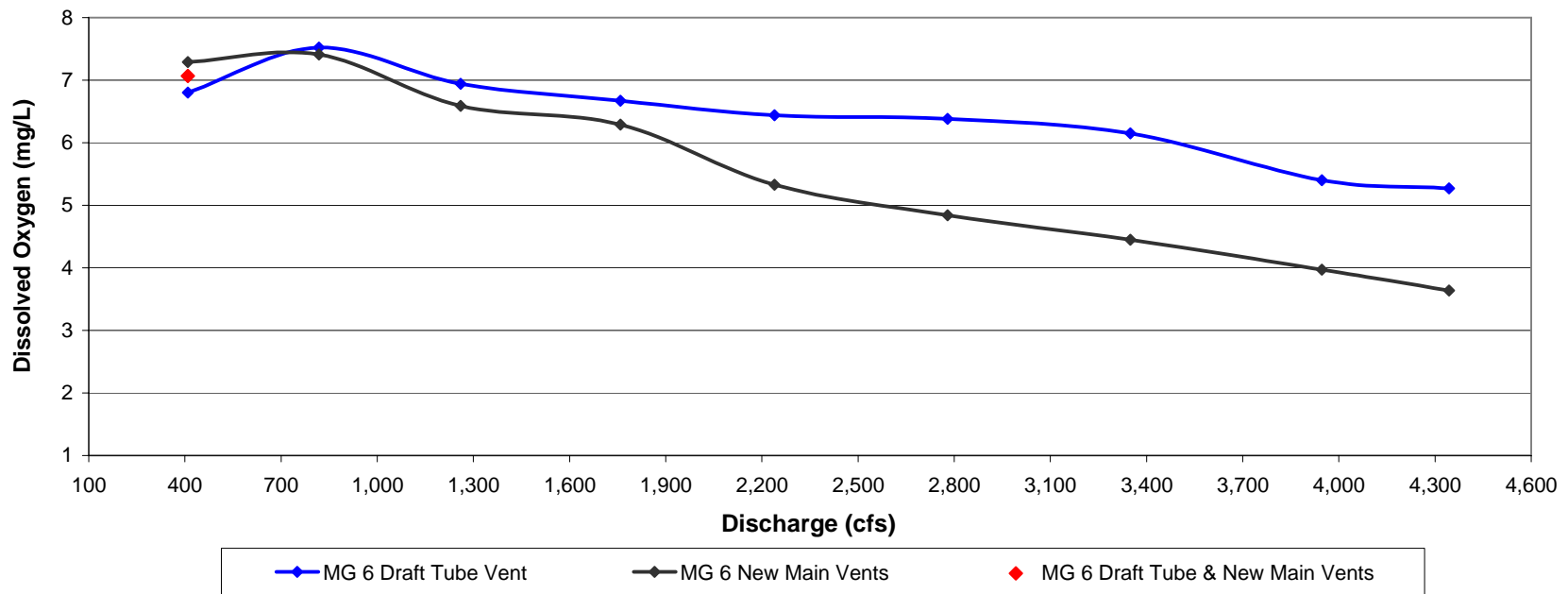
**Figure 29: Relationship between Standard Air Flow and Discharge -
Tailrace Elevation 560 - 2005 Main Generator 3 and 6**



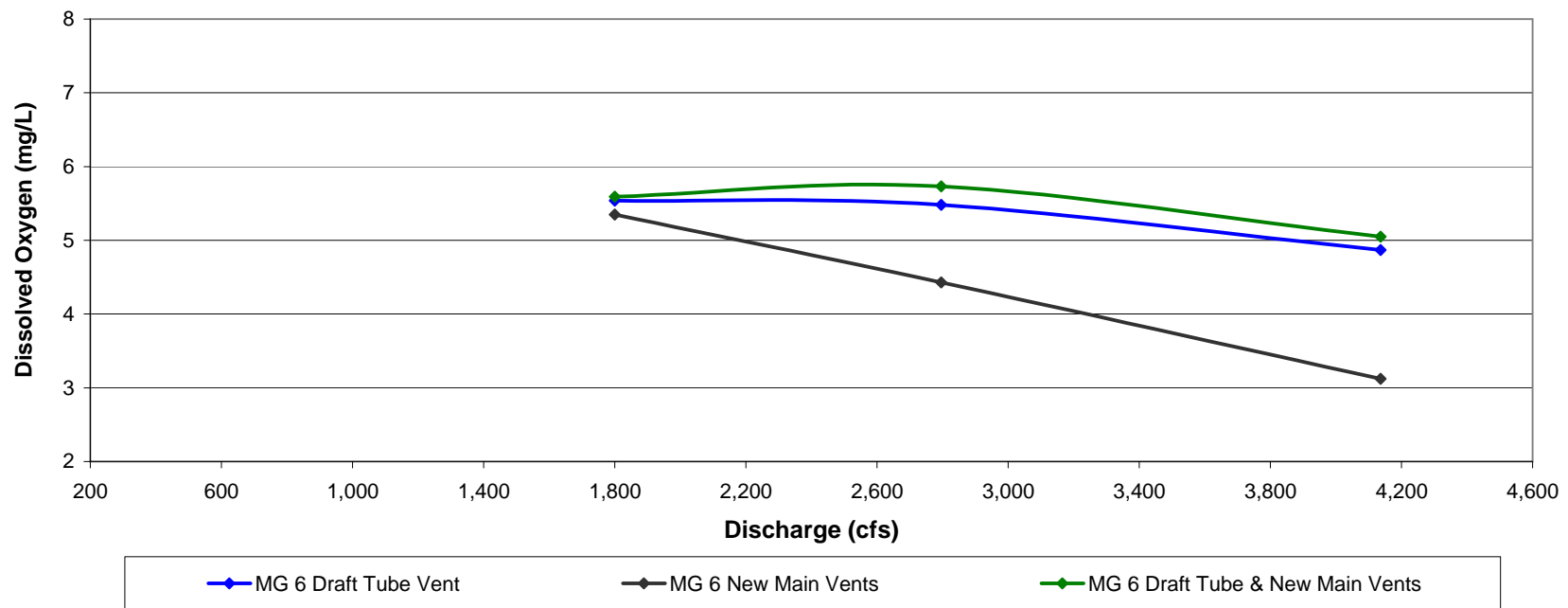
**Figure 30: Relationship between Standard Air Flow and Discharge -
Tailrace Elevation 563 - 2005 Main Generator 3 and 6**



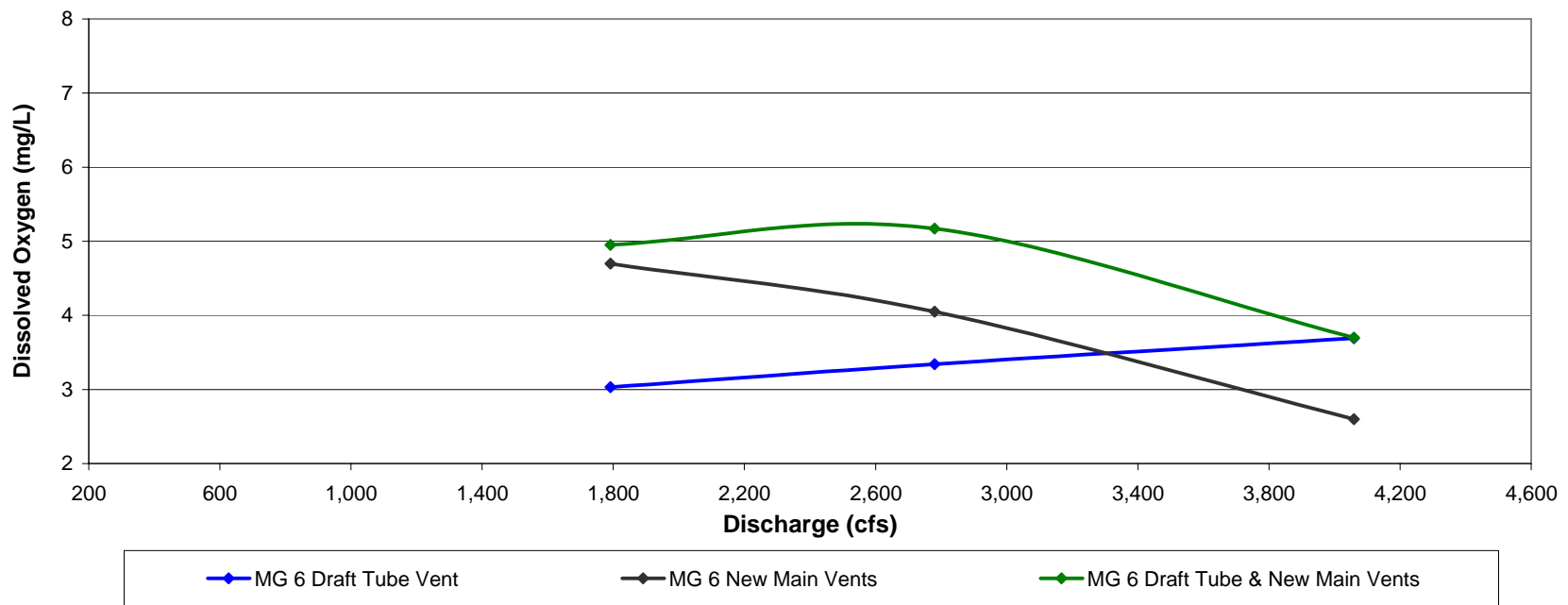
**Figure 31: Relationship between Discharge DO and Discharge -
Tailrace Elevation 553 - 2005 Main Generator 6**



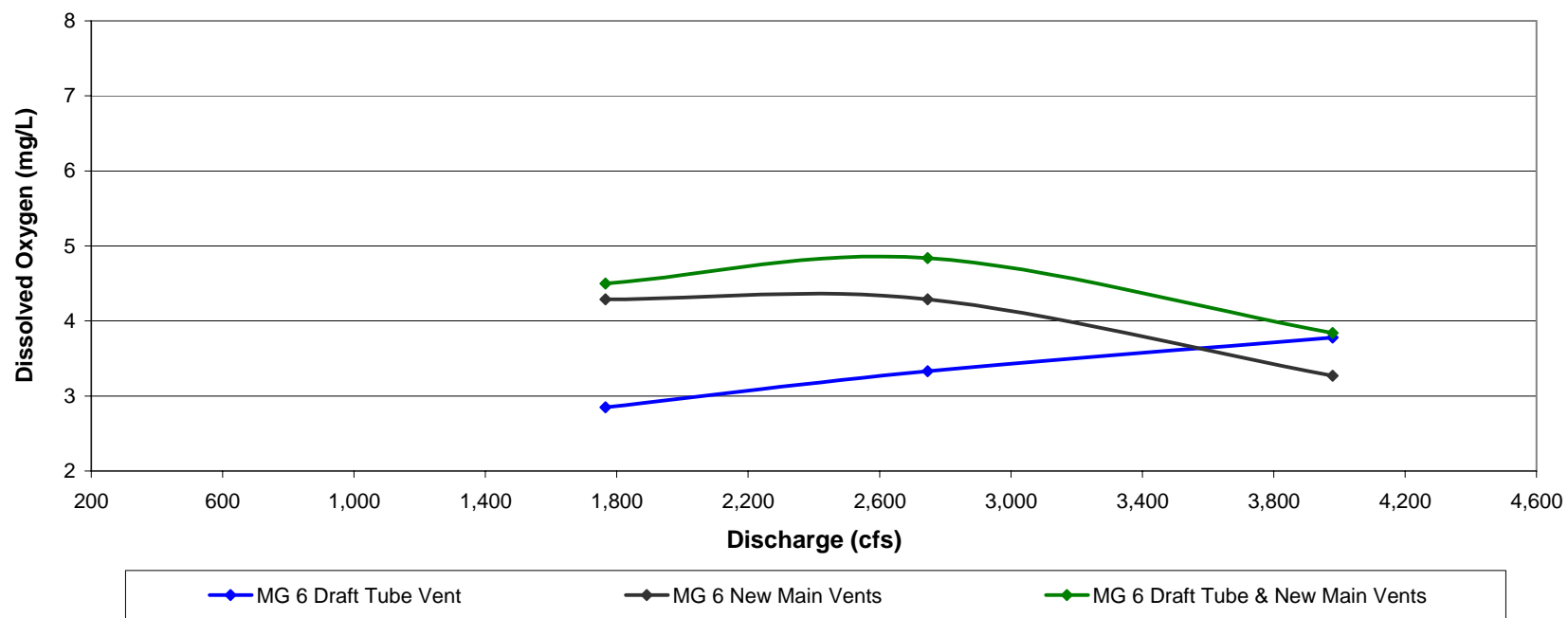
**Figure 32: Relationship between Discharge DO and Discharge -
Tailrace Elevation 556 - 2005 Main Generator 6**



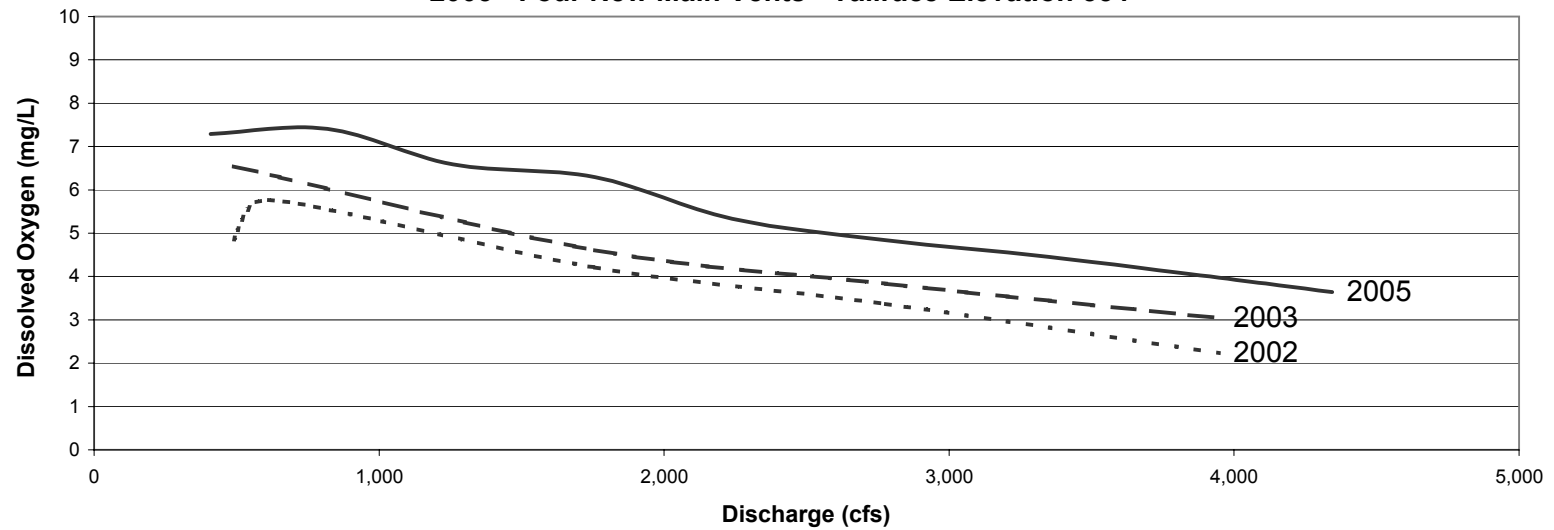
**Figure 33: Relationship between Discharge DO and Discharge -
Tailrace Elevation 560 - 2005 Main Generator 6**



**Figure 34: Relationship between Discharge DO and Discharge -
Tailrace Elevation 563 - 2005 Main Generator 6**



**Figure 35: Relationship between Discharge DO and Discharge -
Main Generator 6 - 2002 & 2003 - Two Original Main Vents &
2005 - Four New Main Vents - Tailrace Elevation 554**

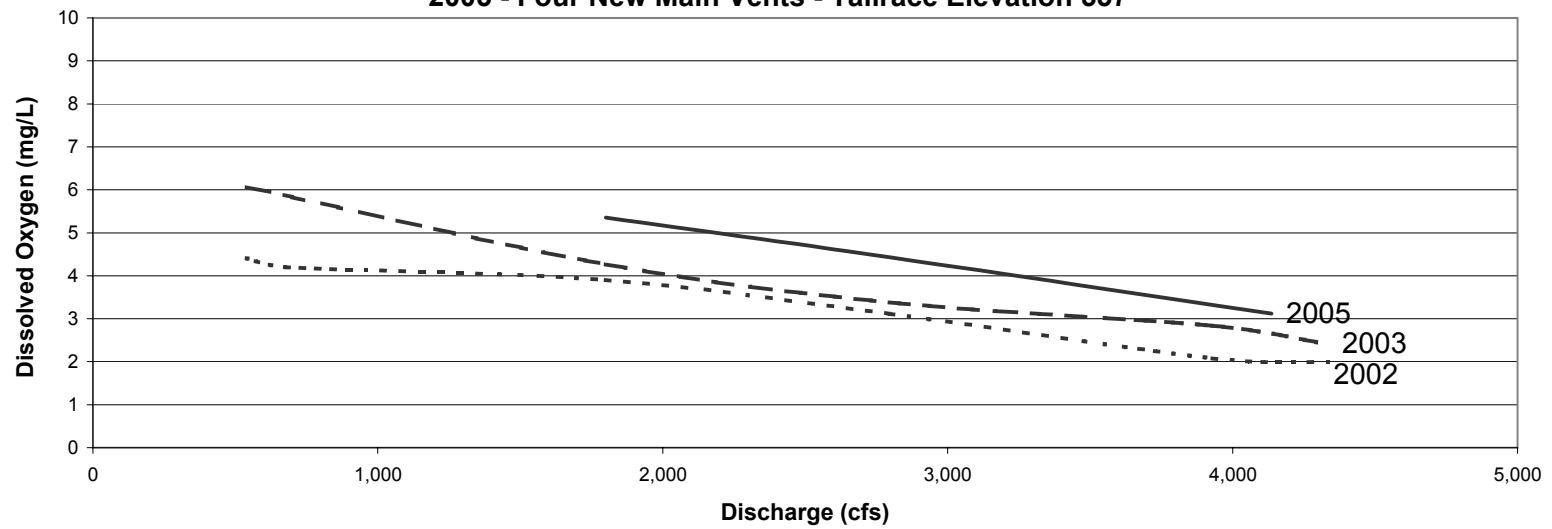


- - - 2002

- - - 2003

— 2005

**Figure 36: Relationship between Discharge DO and Discharge -
Main Generator 6 - 2002 & 2003 - Two Original Main Vents &
2005 - Four New Main Vents - Tailrace Elevation 557**

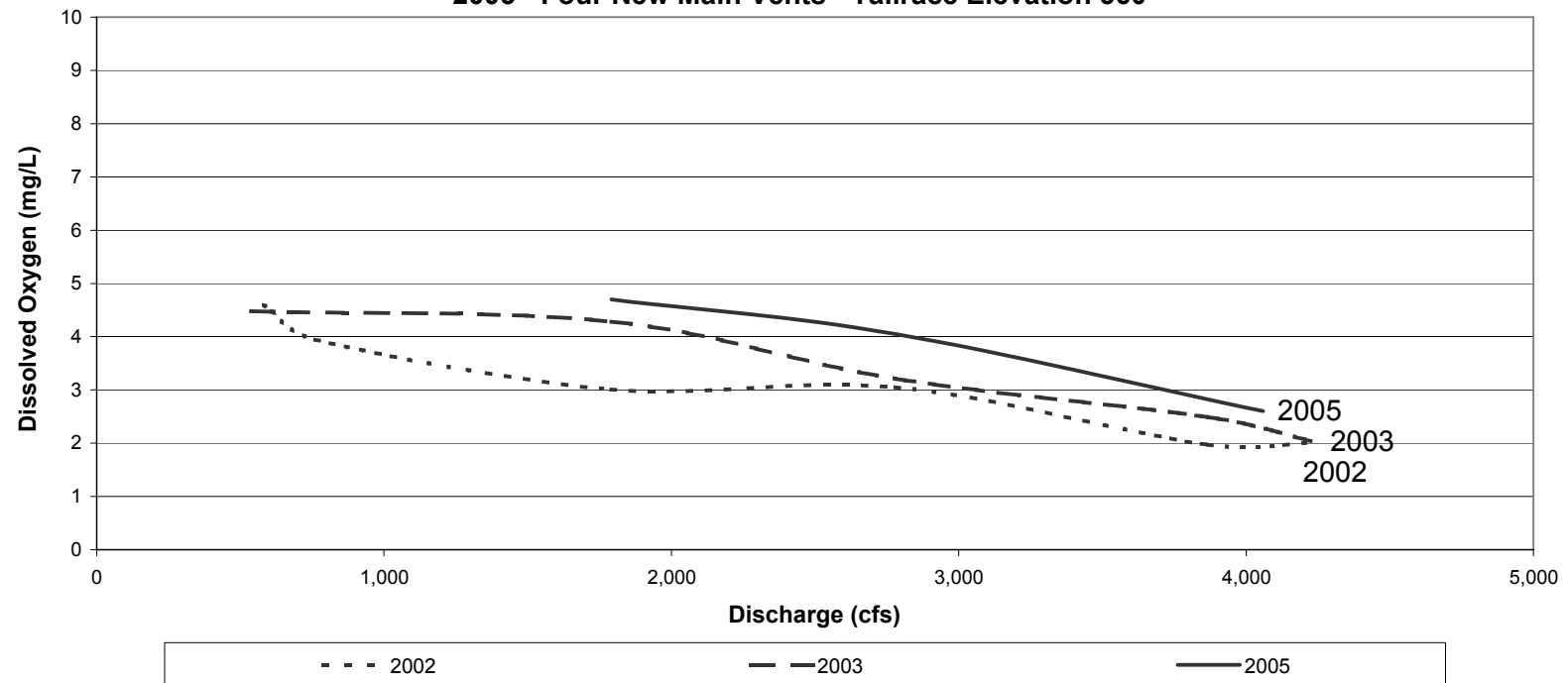


- - - 2002

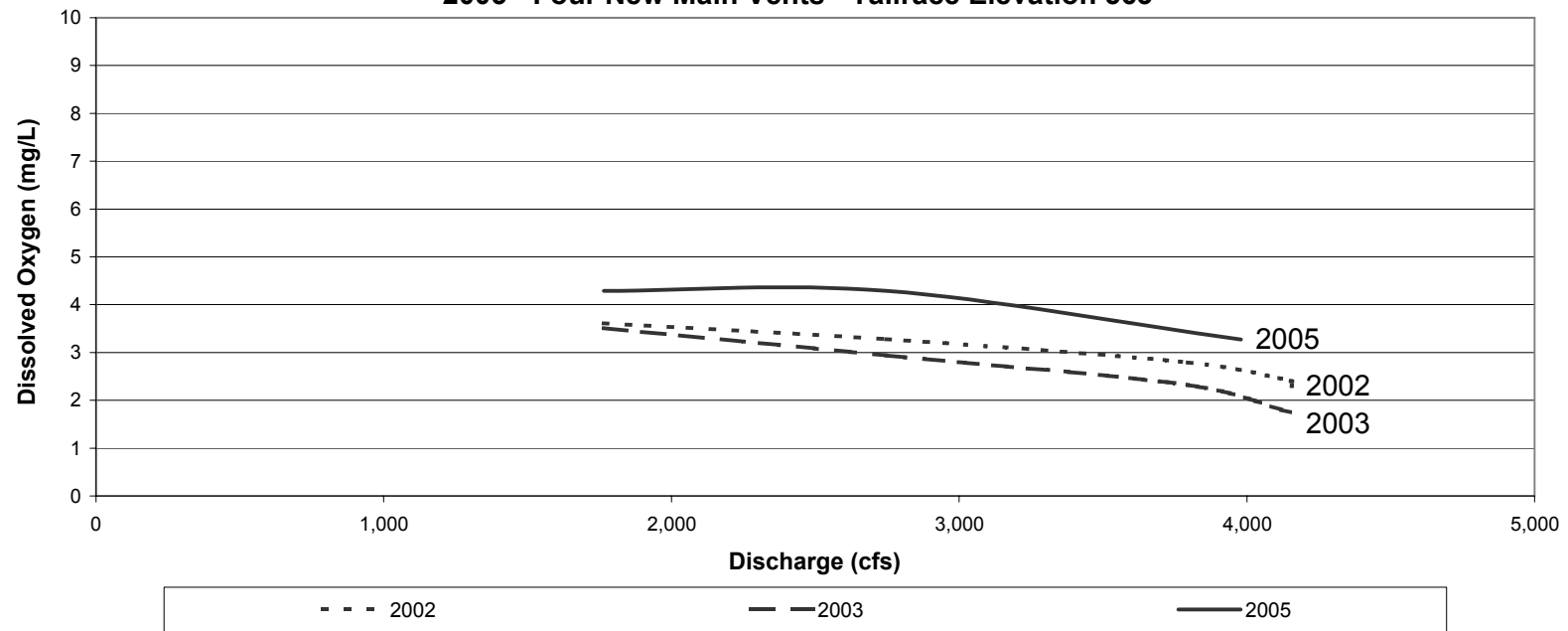
- . - 2003

— 2005

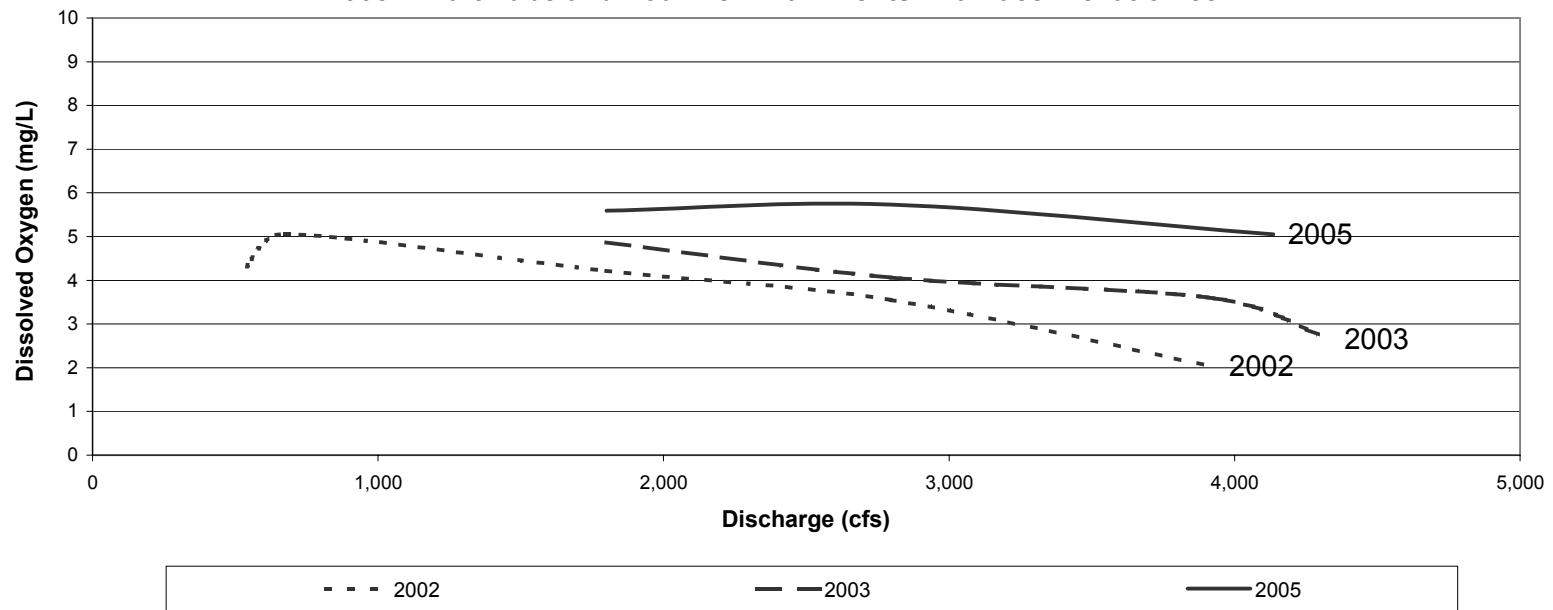
**Figure 37: Relationship between Discharge DO and Discharge -
Main Generator 6 - 2002 & 2003 - Two Original Main Vents &
2005 - Four New Main Vents - Tailrace Elevation 560**



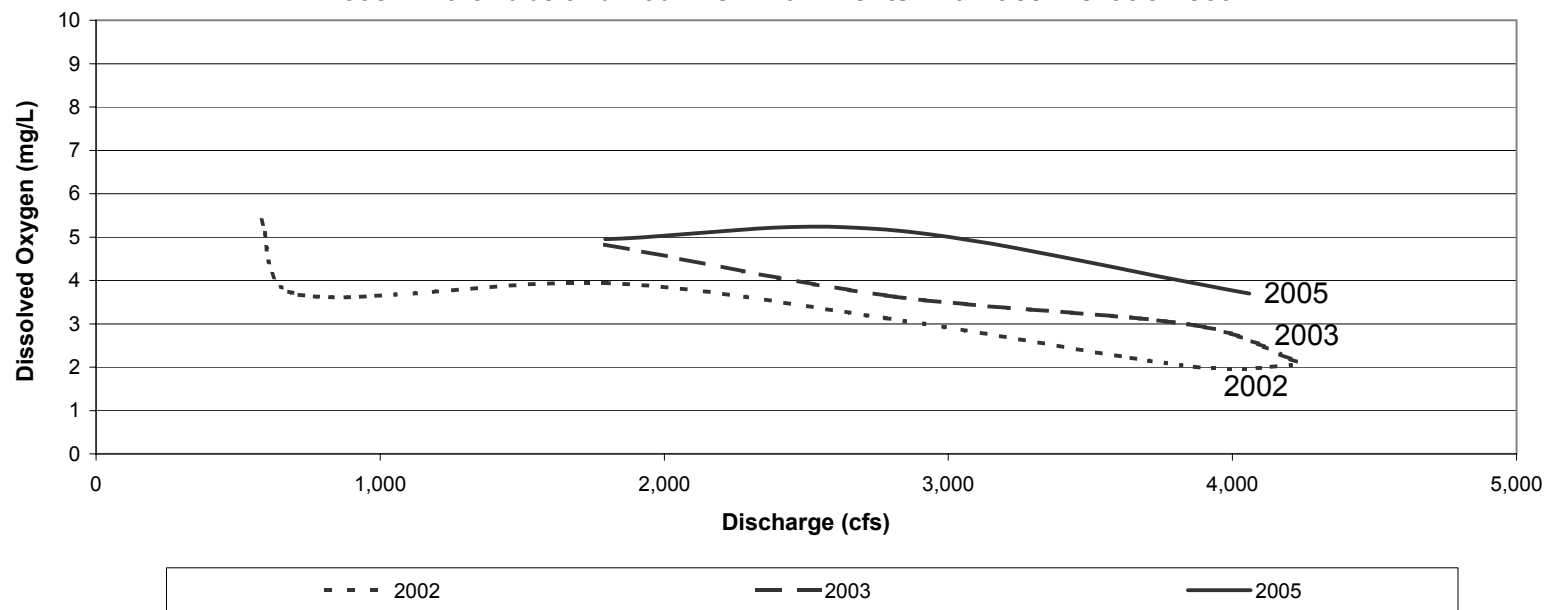
**Figure 38: Relationship between Discharge DO and Discharge -
Main Generator 6 - 2002 & 2003 - Two Original Main Vents &
2005 - Four New Main Vents - Tailrace Elevation 563**



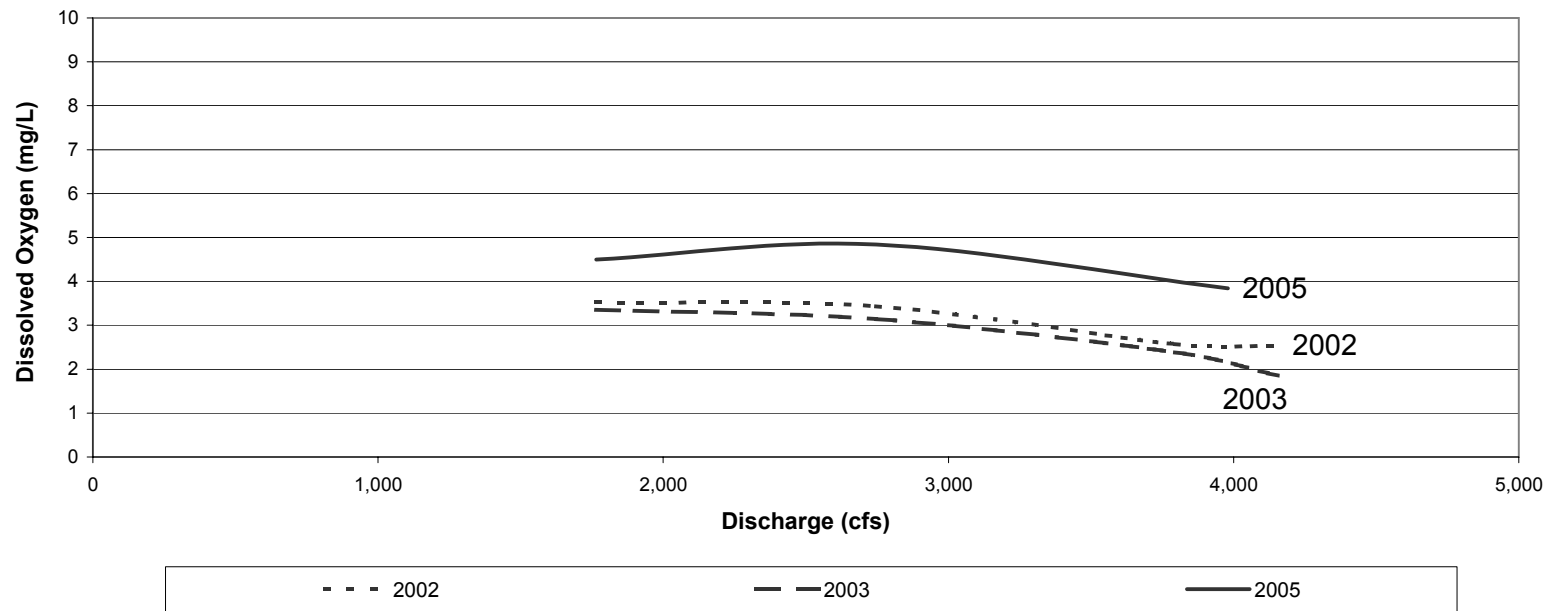
**Figure 39: Relationship between Discharge DO and Discharge -
Main Generator 6 - 2002 & 2003 - Auxiliary Vents and Two Original Main Vents &
2005 - Draft Tube and Four New Main Vents - Tailrace Elevation 557**



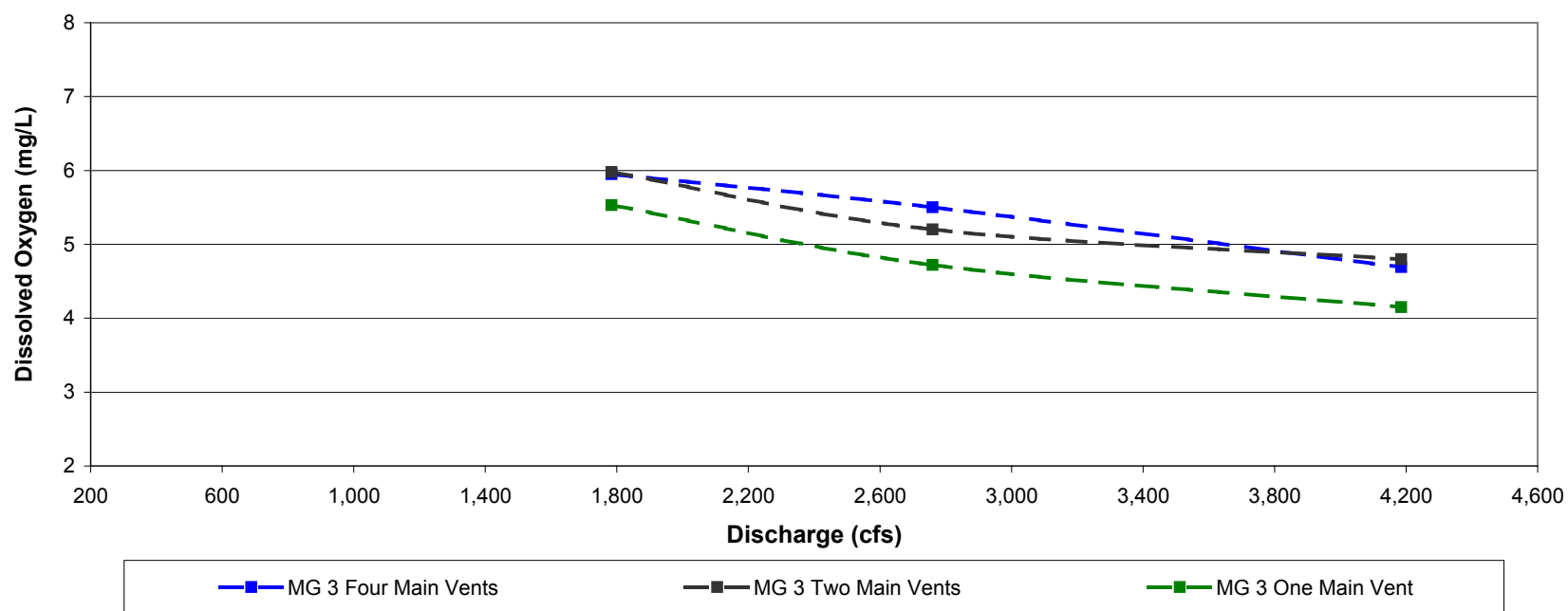
**Figure 40: Relationship between Discharge DO and Discharge -
Main Generator 6 - 2002 & 2003 - Auxiliary Vents and Two Original Main Vents &
2005 - Draft Tube and Four New Main Vents - Tailrace Elevation 560**



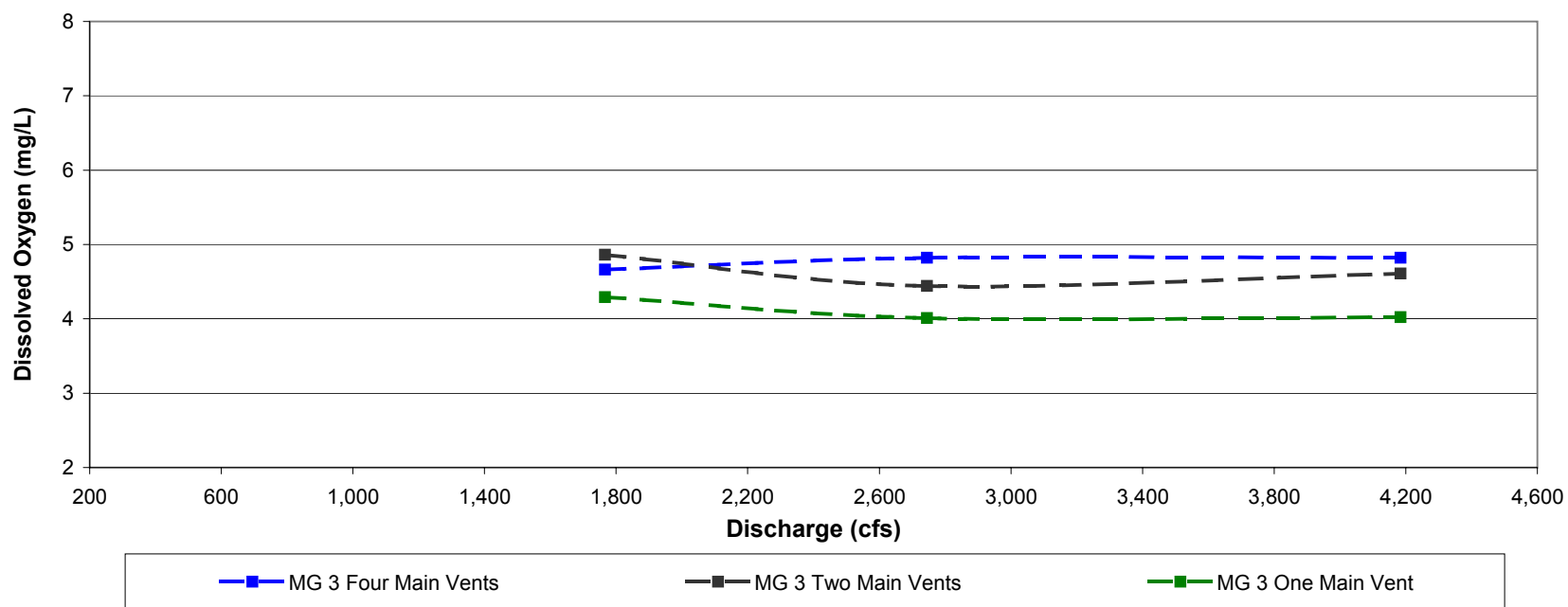
**Figure 41: Relationship between Discharge DO and Discharge -
Main Generator 6 - 2002 & 2003 - Auxiliary Vents and Two Original Main Vents &
2005 - Draft Tube and Four New Main Vents - Tailrace Elevation 563**



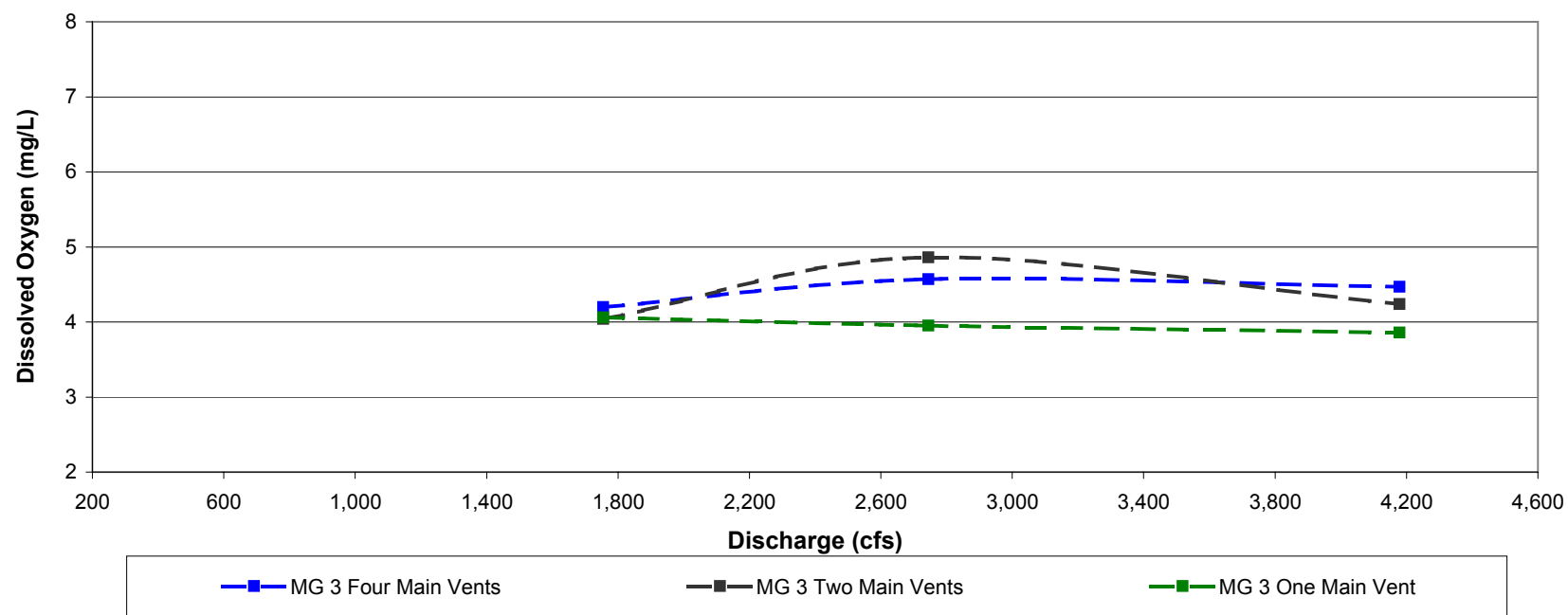
**Figure 42: Relationship between Discharge DO and Discharge -
Tailrace Elevation 556 - 2005 Main Generator 3**



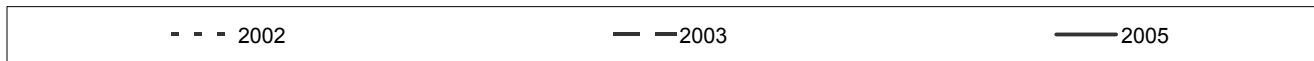
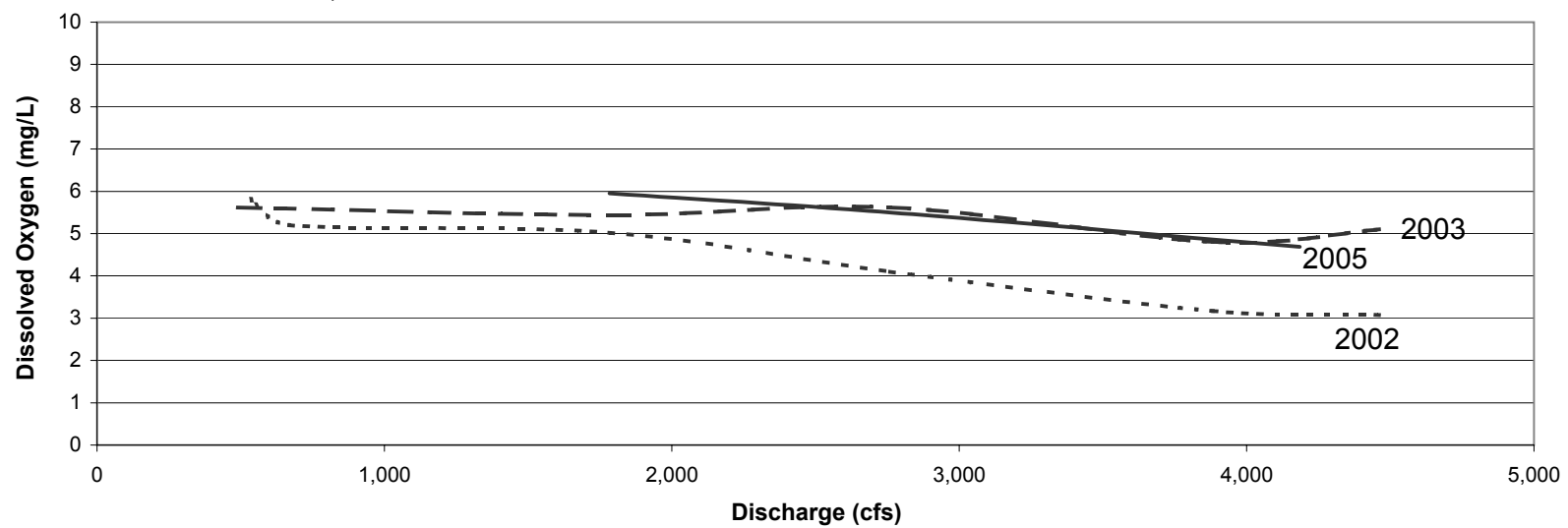
**Figure 43: Relationship between Discharge DO and Discharge -
Tailrace Elevation 560 - 2005 Main Generator 3**



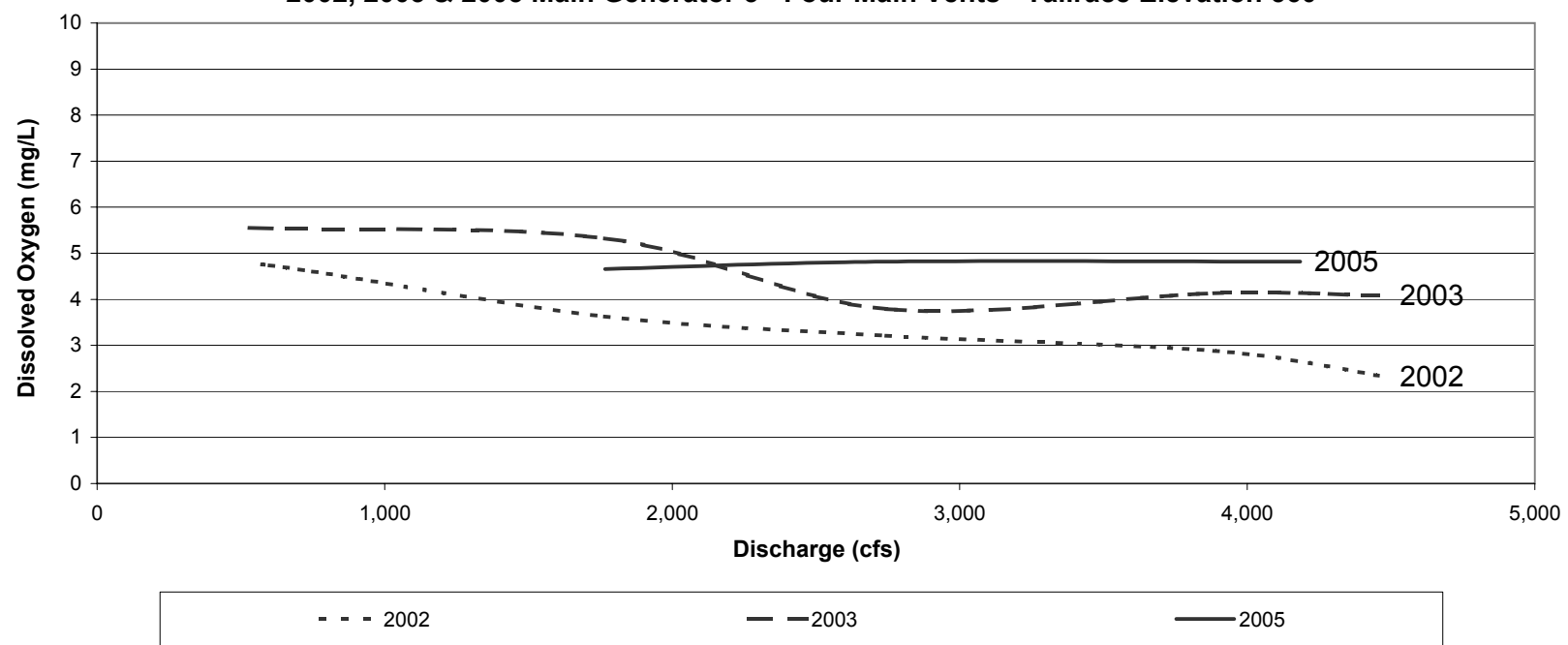
**Figure 44: Relationship between Discharge DO and Discharge -
Tailrace Elevation 563 - 2005 Main Generator 3**



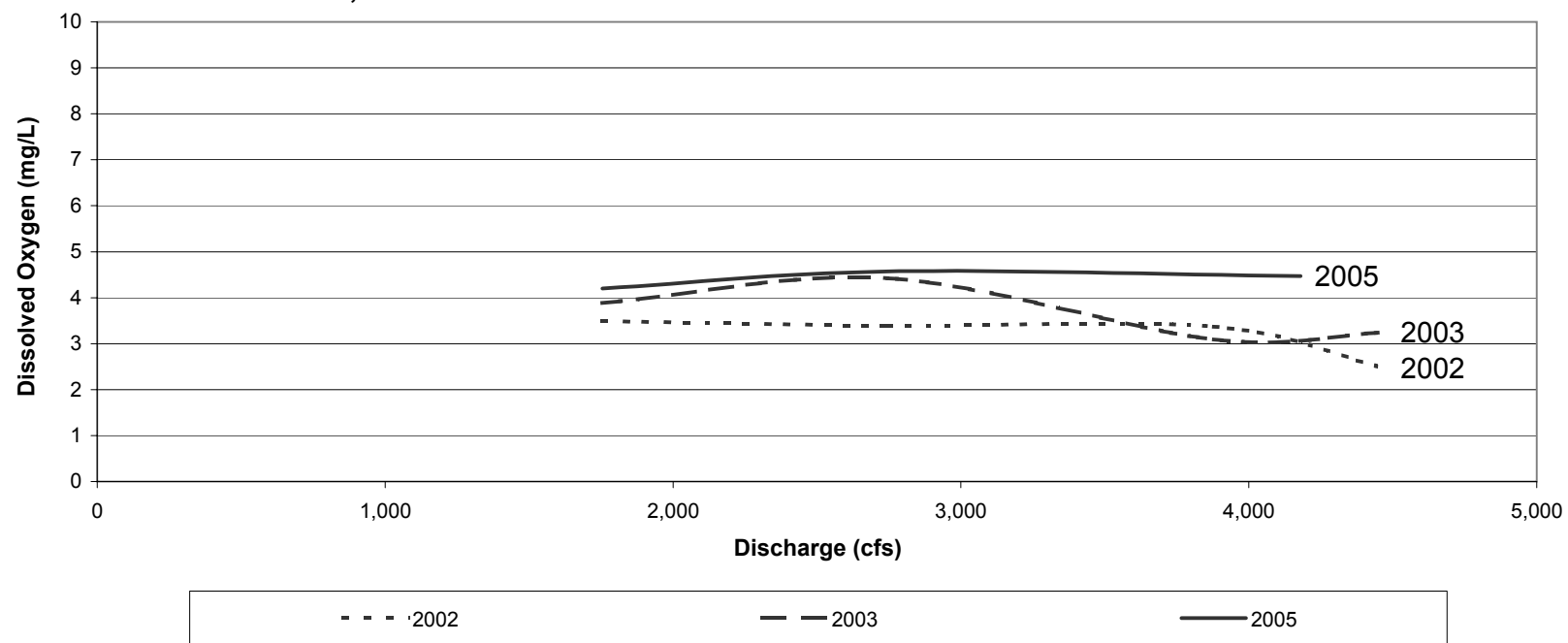
**Figure 45: Relationship between Discharge DO and Discharge -
2002, 2003 & 2005 Main Generator 3 - Four Main Vents - Tailrace Elevation 557**



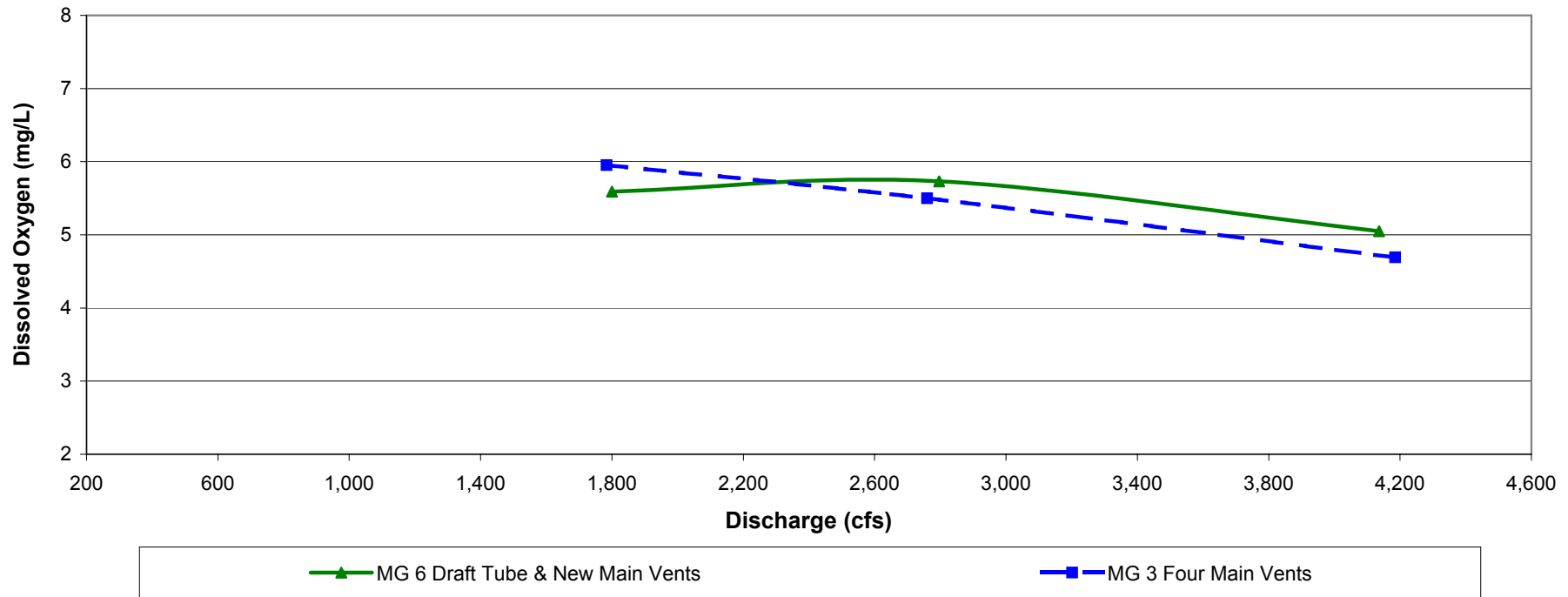
**Figure 46: Relationship between Discharge DO and Discharge -
2002, 2003 & 2005 Main Generator 3 - Four Main Vents - Tailrace Elevation 560**



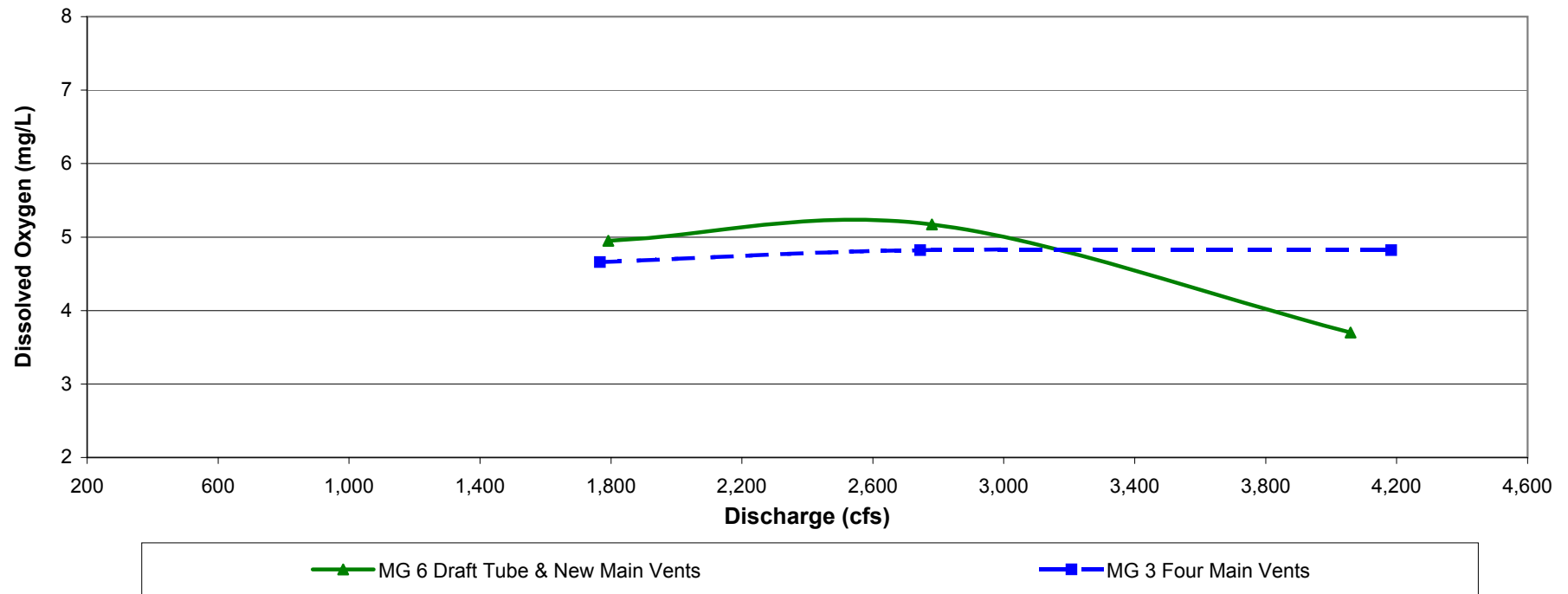
**Figure 47: Relationship between Discharge DO and Discharge -
2002, 2003 & 2005 Main Generator 3 - Four Main Vents - Tailrace Elevation 563**



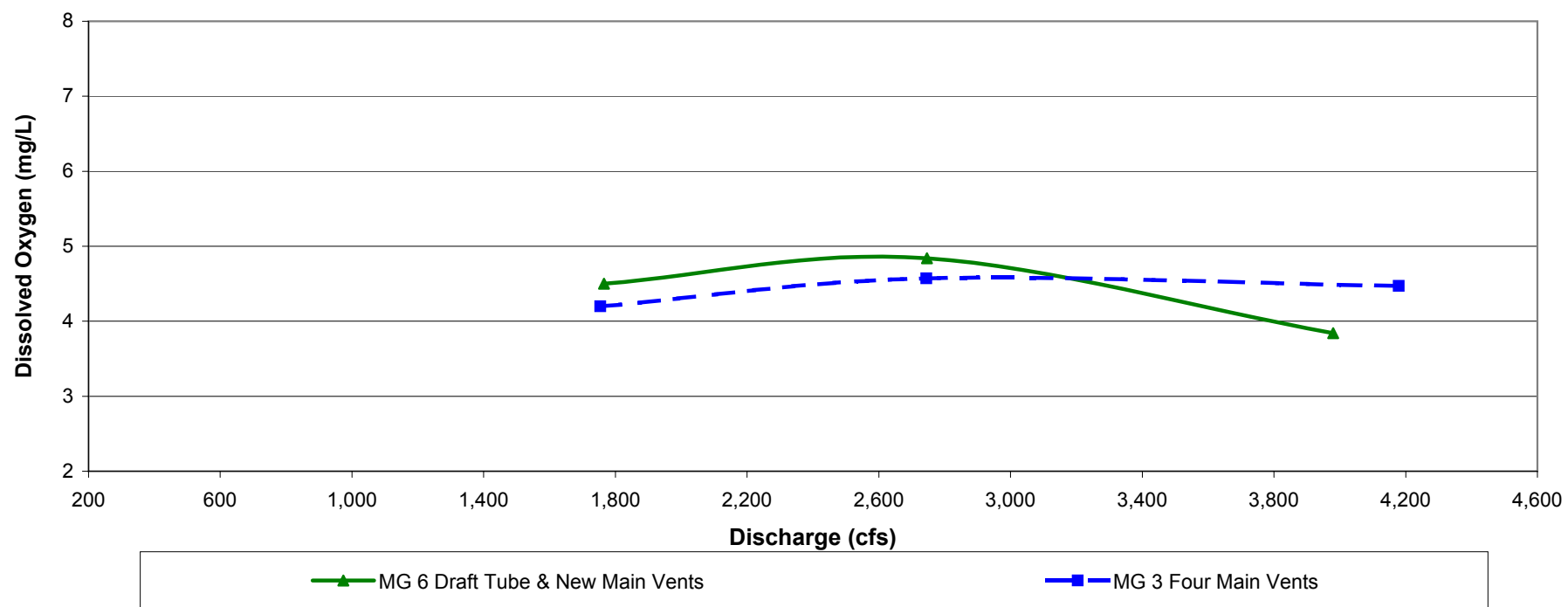
**Figure 48: Relationship between Discharge DO and Discharge -
Tailrace Elevation 556 - 2005 Main Generator 3 and 6**



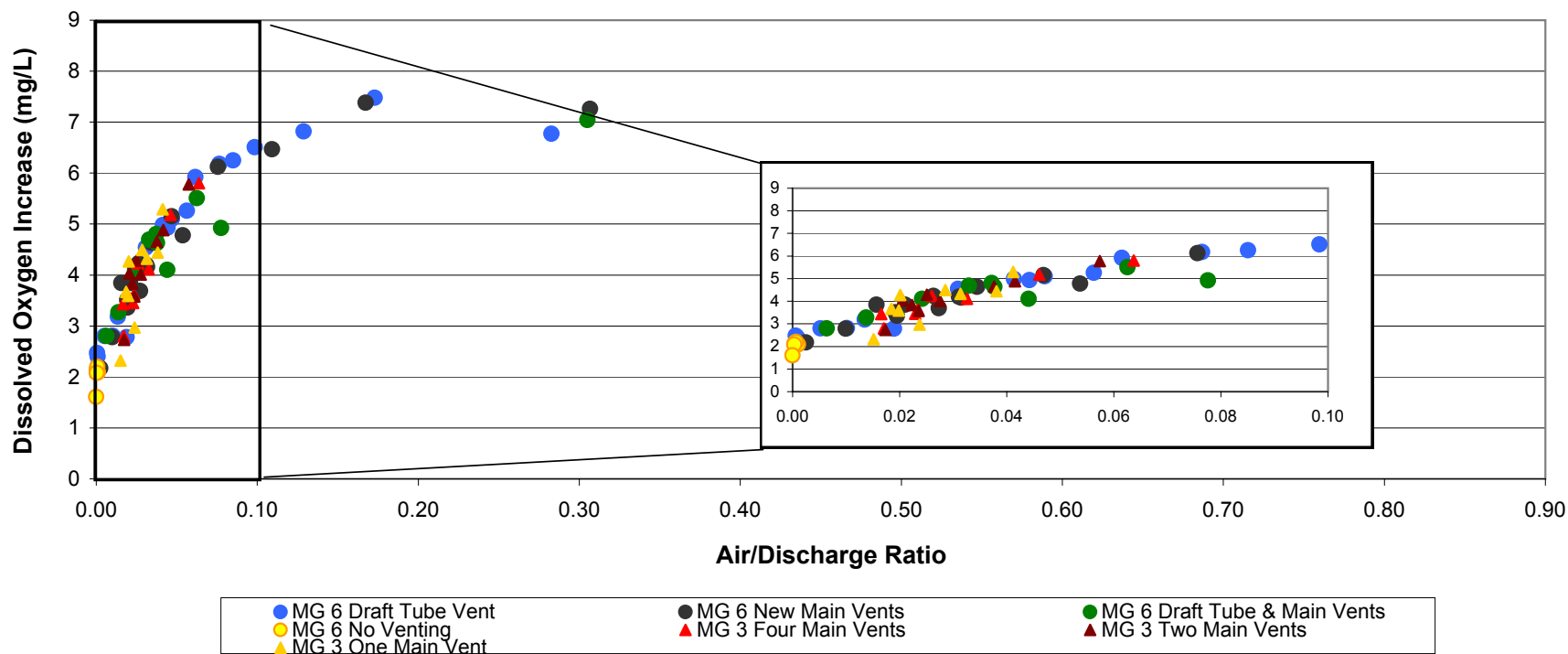
**Figure 49: Relationship between Discharge DO and Discharge -
Tailrace Elevation 560 - 2005 Main Generator 3 and 6**



**Figure 50: Relationship between Discharge DO and Discharge -
Tailrace Elevation 563 - 2005 Main Generators 3 and 6**

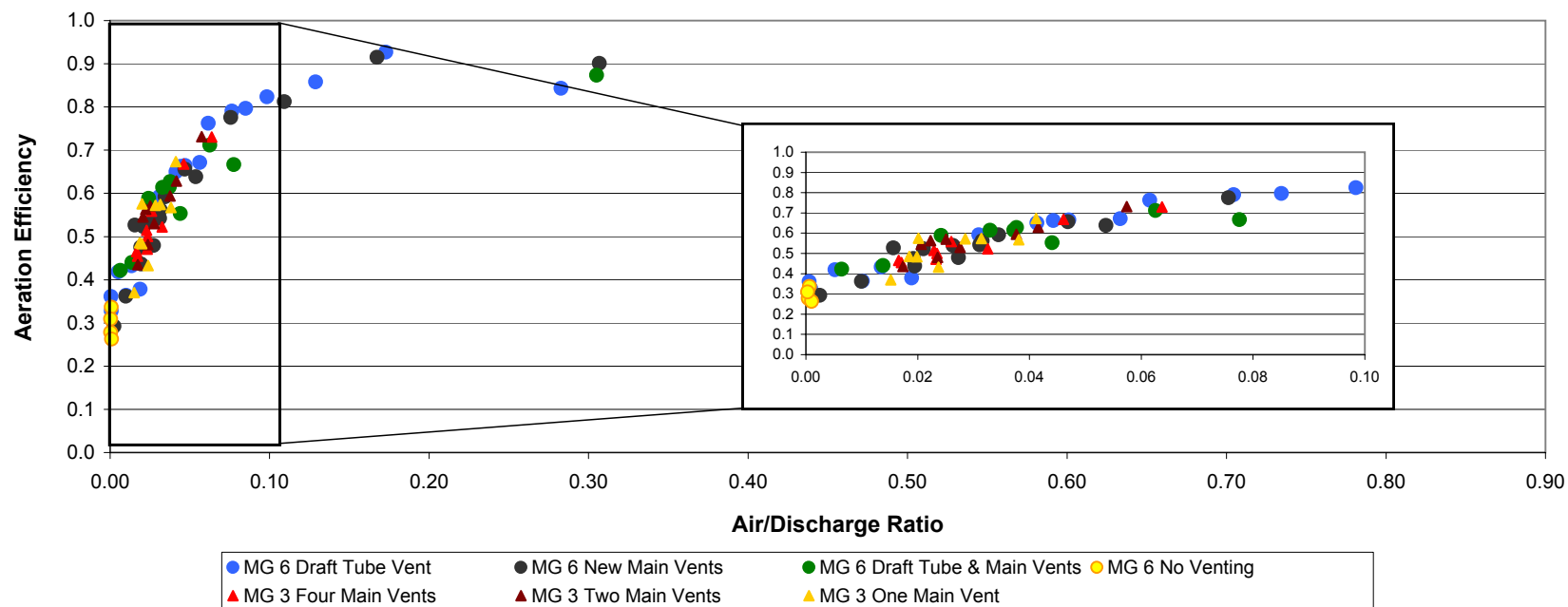


**Figure 51: Relationship between Dissolved Oxygen Increase
and Air:Discharge Ratio - Main Generator 3 & 6 - 7/26/05 & 7/27/05**



Dissolved Oxygen Increase is the difference between the study unit discharge dissolved oxygen and the study unit intake dissolved oxygen.

**Figure 52: Relationship between Aeration Efficiency
and Air:Discharge Ratio - Main Generator 3 & 6 - 7/26/05 & 7/27/05**



Aeration Efficiency is the ability of the study unit to increase the inlet water dissolved oxygen concentrations to saturation concentrations. Aeration Efficiency = $(C_D - C_i) / (C_s - C_i)$ where C_D = Dissolved Oxygen Concentration in the Discharge Water, and C_i = Dissolved Oxygen Concentration in the Inlet Water, and C_s = Dissolved Oxygen Concentration at Saturation

Figure 53: Relationship between Oxygen Transfer Efficiency and Air:Discharge Ratio - Main Generator 3 & 6 - 7/26/05 & 7/27/05

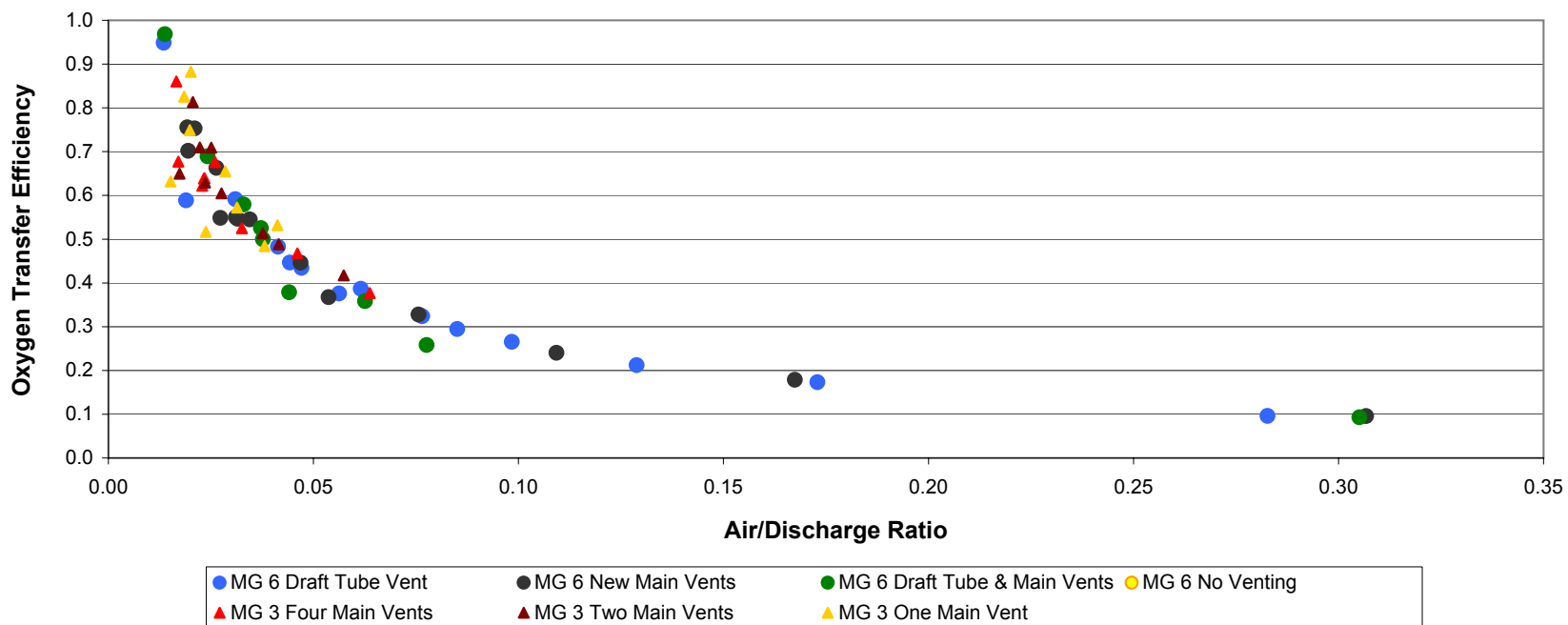
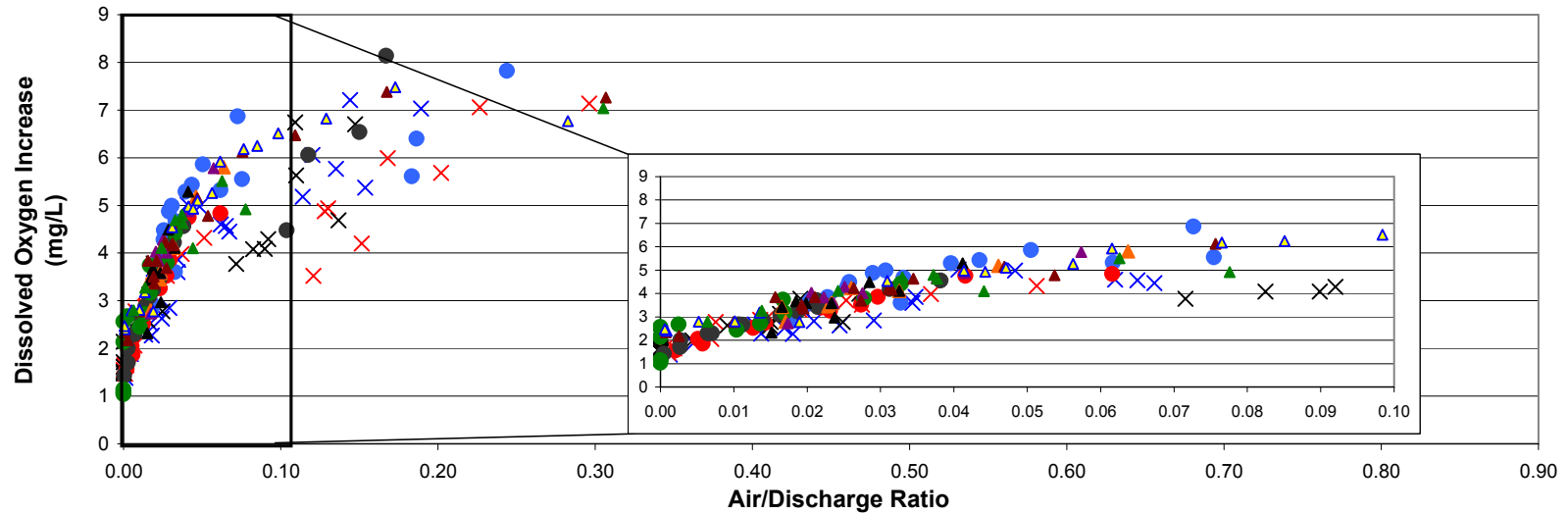


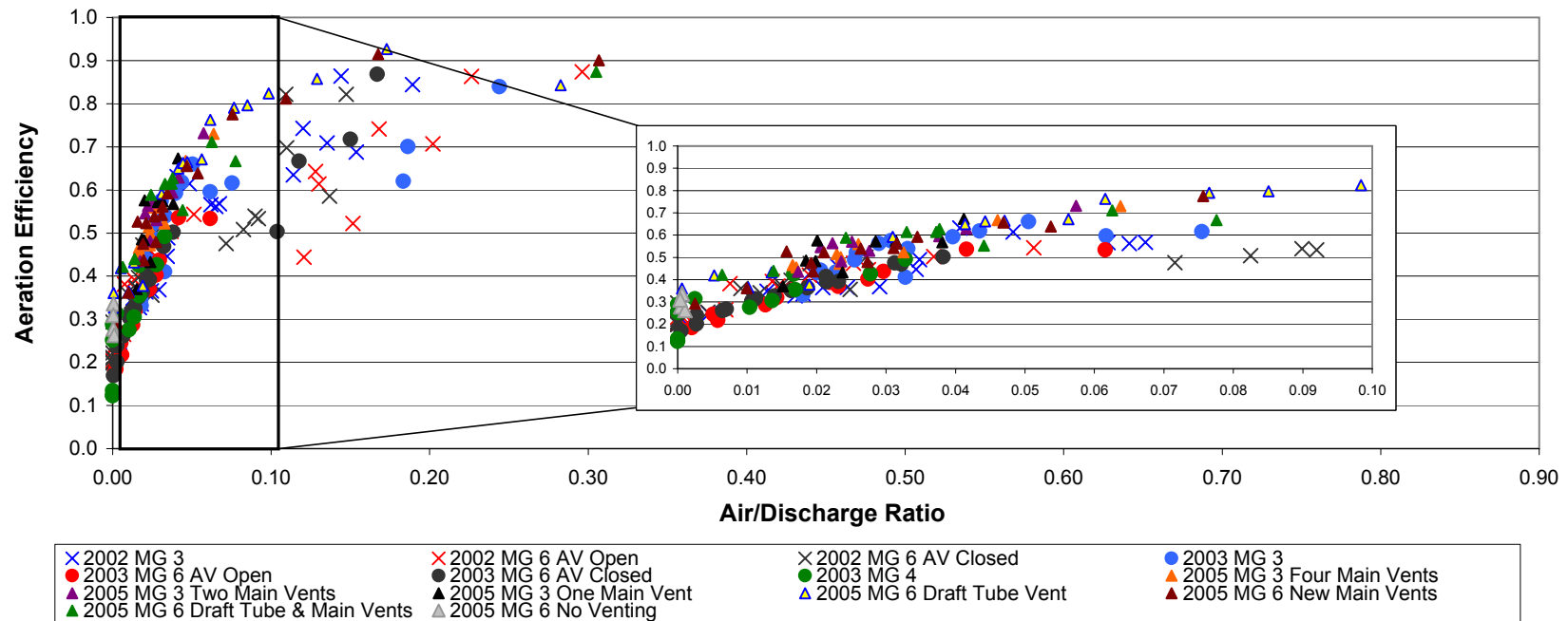
Figure 54: Relationship between Dissolved Oxygen Increase and Air:Discharge Ratio - MG 3 & 6 - 2002, 2003 & 2005



Note: **AVO** - Auxillary Vents Open, **AVC** - Auxillary Vents Closed, **DTO** - Draft Tube Vents Open, **DTC** - Draft Tube Vents Closed

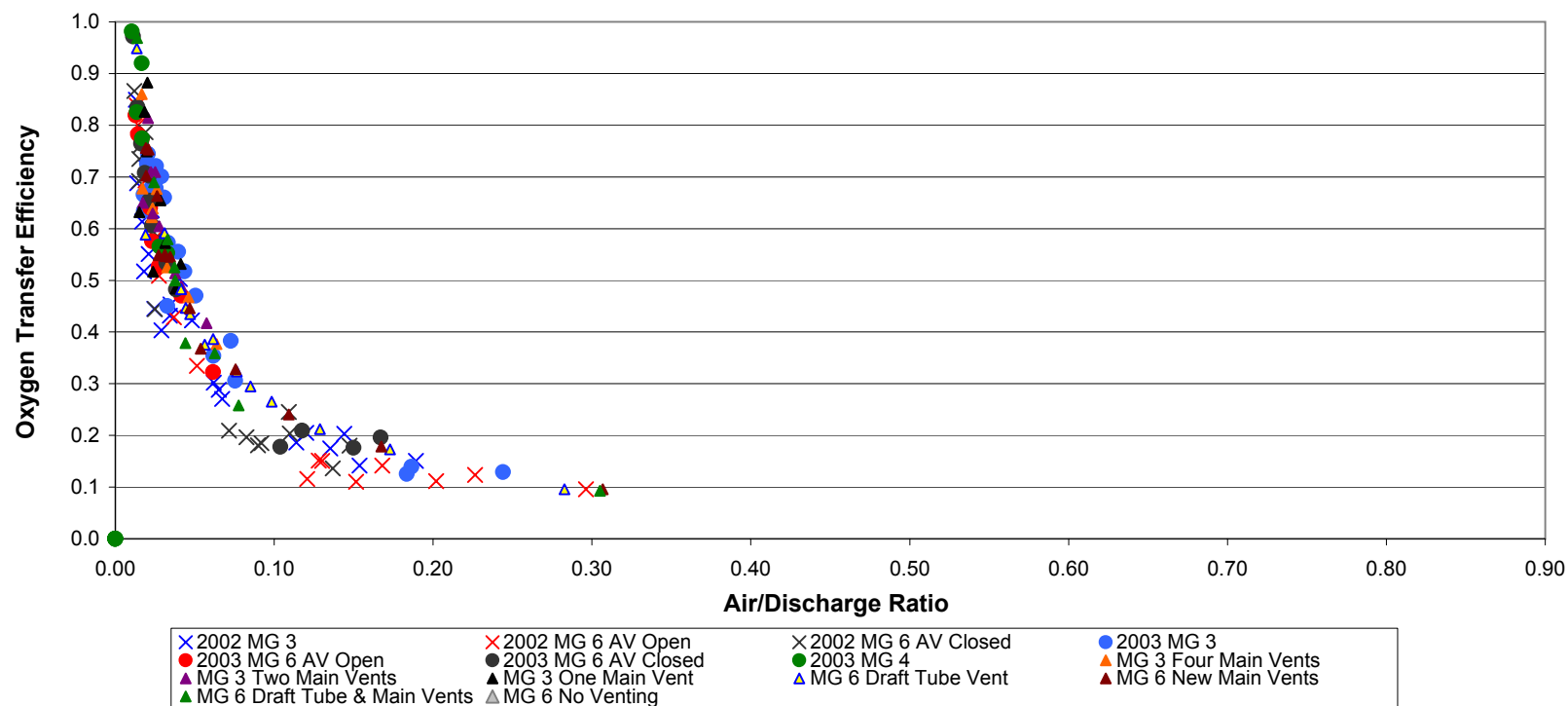
Dissolved Oxygen Increase is the difference between the tailrace dissolved oxygen and the intake dissolved oxygen.

**Figure 55: Relationship between Aeration Efficiency
and Air:Discharge Ratio - Main Generator 3, 4 & 6 - 2002, 2003 & 2005**



Aeration Efficiency is the ability of the study unit to increase the inlet water dissolved oxygen concentrations to saturation concentrations. Aeration Efficiency = $(C_D - C_i) / (C_S - C_i)$ where C_D = Dissolved Oxygen Concentration in the Discharge Water, and C_i = Dissolved Oxygen Concentration in the Inlet Water, and C_S = Dissolved Oxygen Concentration at Saturation

Figure 56: Relationship between Oxygen Transfer Efficiency and Air:Discharge Ratio - Main Generator 3, 4 & 6 - 2002, 2003 & 2005



Oxygen Transfer Efficiency is a measure of the study unit's ability to transfer oxygen from the air entering the unit into the water entering the unit. Oxygen Transfer Efficiency = Mass of O₂ (lbs) transferred to water/mass of O₂ (lbs) from airflow

Figure 57: Relationship between Total Dissolved Gas and Air:Discharge Ratio - Main Generator 3 & 6 - 7/26/05 & 7/27/05

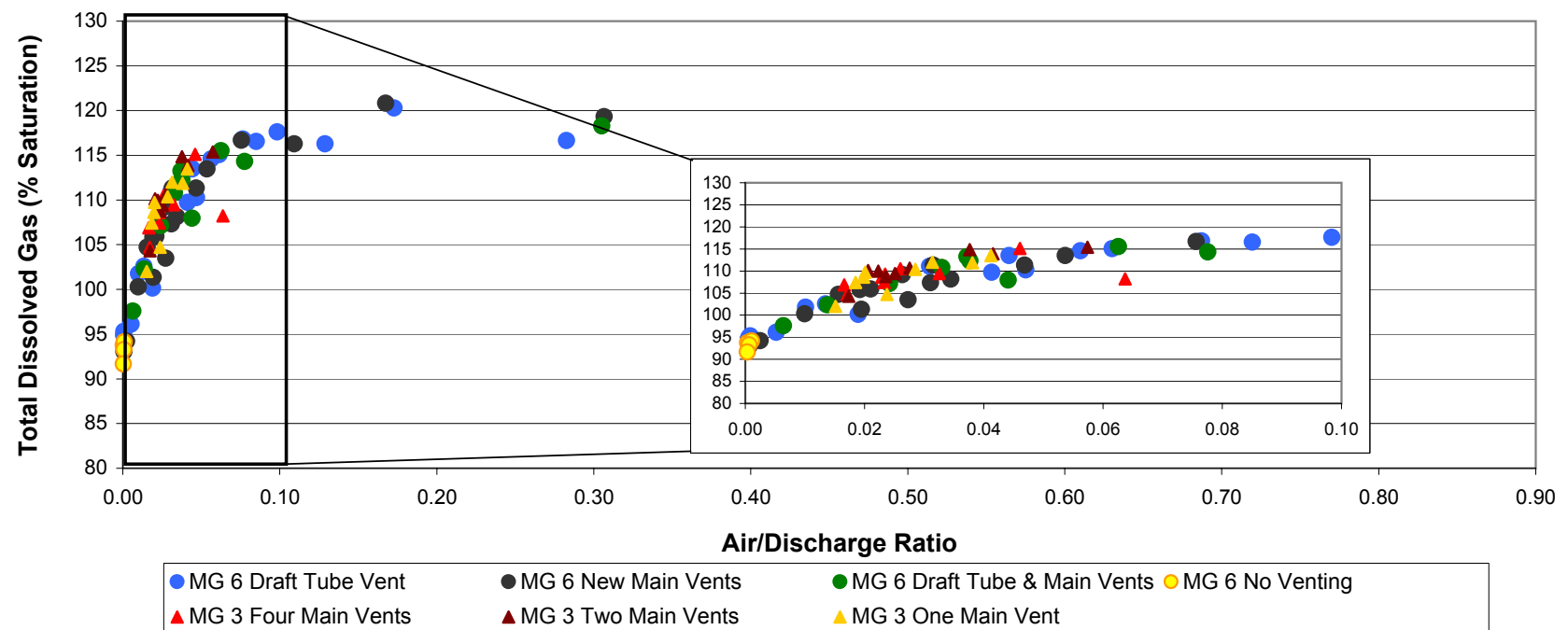
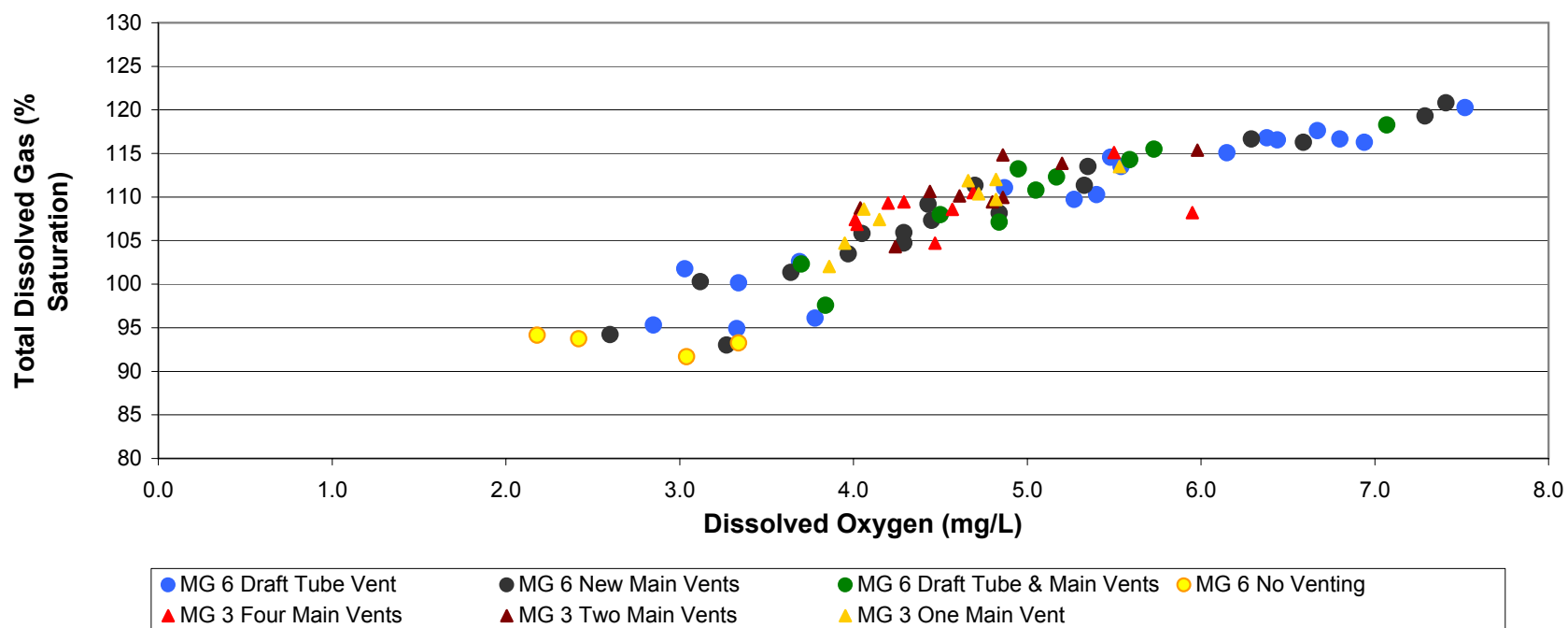
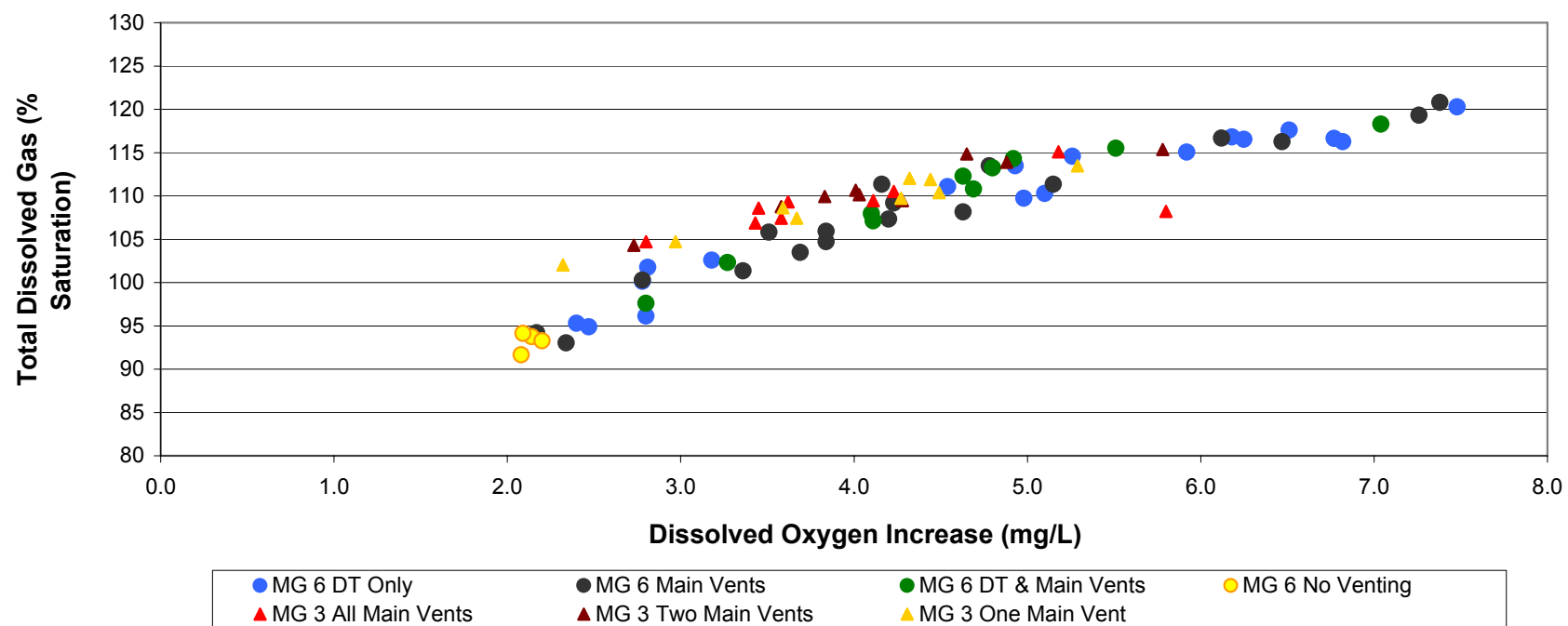


Figure 58: Relationship between Total Dissolved Gas and Discharge Dissolved Oxygen - Main Generator 3 & 6 - 7/26/05 & 7/27/05



Discharge Dissolved Oxygen that which was measured in the discharge boil of the study unit.

Figure 59: Relationship between Total Dissolved Gas and Dissolved Oxygen Increase - Main Generator 3 & 6 - 7/26/05 & 7/27/05



Dissolved Oxygen Increase is the difference between the study unit discharge dissolved oxygen and the study unit intake dissolved oxygen.

**Figure 60: Relationship between Total Dissolved Gas
and Air:Discharge Ratio - Main Generator 3, 4 & 6 - 2002, 2003 and 2005**

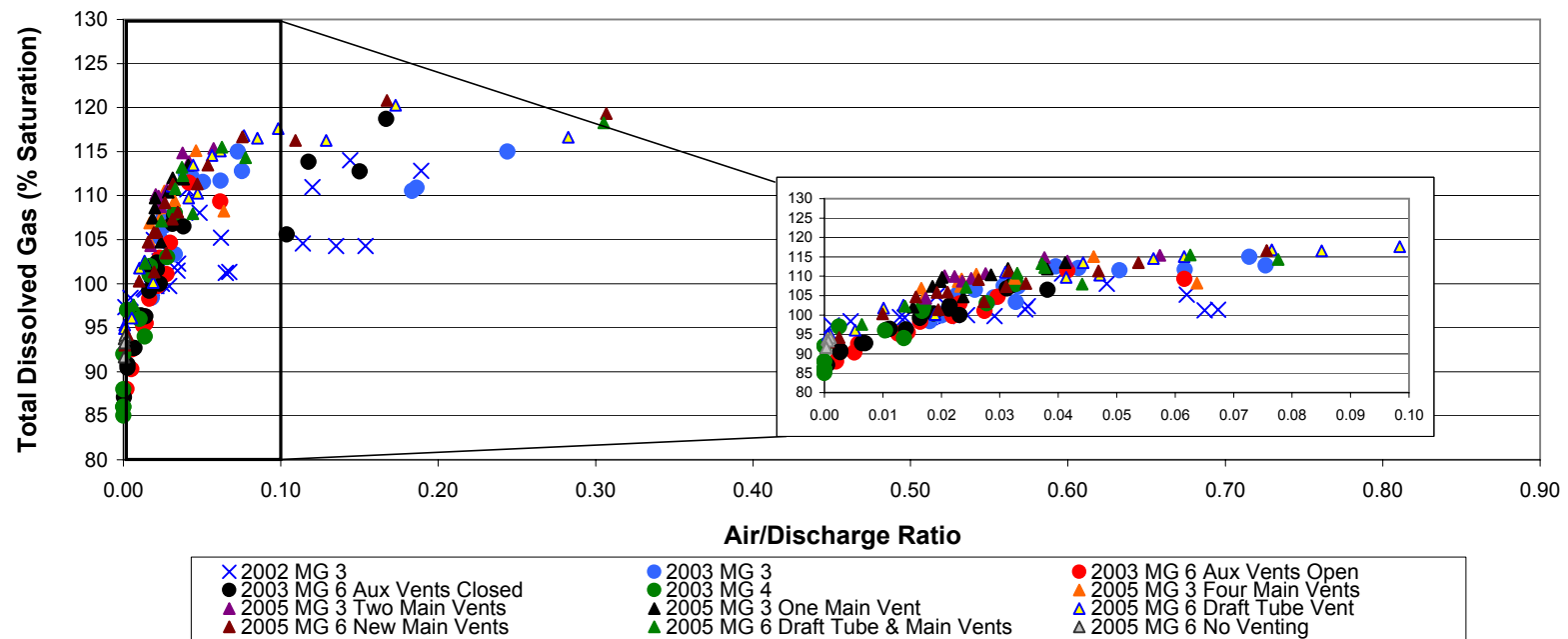
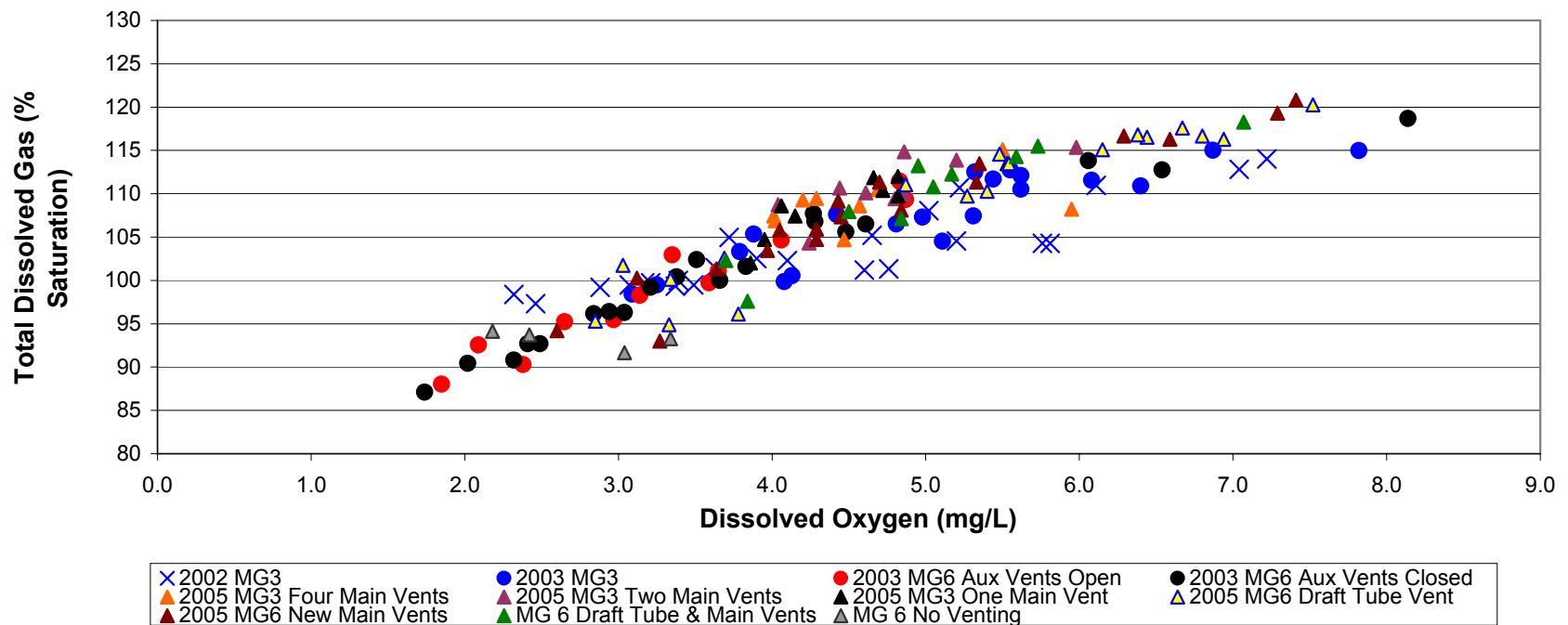
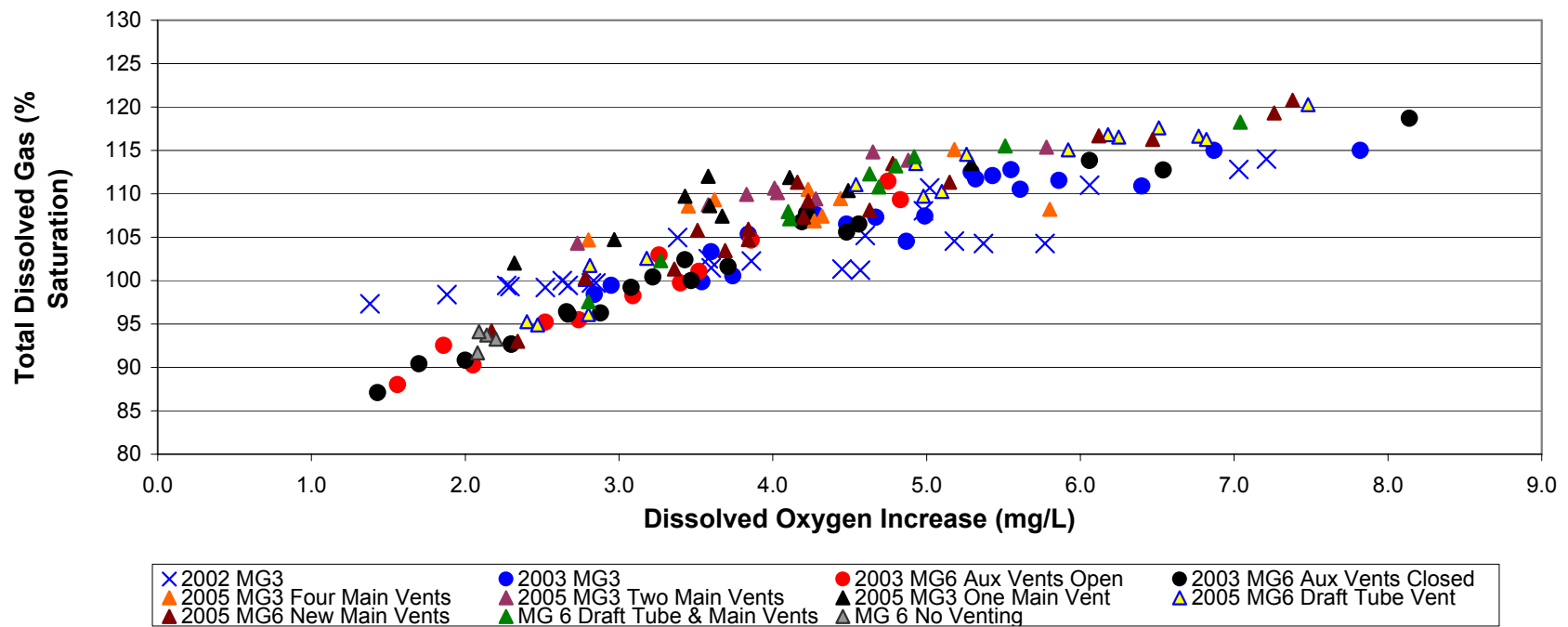


Figure 61: Relationship between Total Dissolved Gas and Discharge Dissolved Oxygen - Main Generator 3 & 6 - 2002, 2003 and 2005



Discharge Dissolved Oxygen that which was measured in the discharge boil of the study unit.

Figure 62: Relationship between Total Dissolved Gas and Dissolved Oxygen Increase - Main Generator 3 & 6 - 2002, 2003 and 2005



Dissolved Oxygen Increase is the difference between the study unit discharge dissolved oxygen and the study unit intake dissolved oxygen.

APPENDIX 2

Table 1: 2002 Main Generator 3 Data

Measured Values													
Run #	Aux Vents Unit 6	Gate Setting %	Tailrace Elev. (feet)	Barometric Pressure mmHg	Barrel 3 Air Flow Data							Discharge (cfs)	Tailrace Water Temp (°C)
					Air Temp (°C)	Vent 1 (cfm)	Vent 2 (cfm)	Vent 3 (cfm)	Vent 4 (cfm)	Total (cfm)	Stdnd (scfm)		
1a	Closed	1MW	551.52	749	29	5,100	4,600	4,633	5,045	6,475	6,090	537	23.6
1a	Closed	1MW	551.52									537	
2a	Open	2MW	551.61	749	29	5,340	4,860	4,873	5,491	6,986	6,570	760	23.5
2a	Open	2MW	551.61									760	
7a	Closed	1MW	553.57	748	29	4,216	3,932	4,028	4,645	5,703	5,360	581	24.4
8a	Closed	2MW	554.18	747	29	4,326	4,044	4,147	4,702	5,843	5,480	760	24.3
9a	Closed	40%	554.18	747	30	5,472	5,011	4,977	5,550	7,111	6,650	1,788	24.5
10b	Open	60%	554.09	748	30	5,548	5,089	5,041	5,573	7,213	6,760	2,772	24.7
11a	Closed	80%	554.26	747	31	4,330	4,140	4,185	4,888	5,797	5,400	3,909	24.9
12a	Closed	90%	554.44	747	31	4,068	3,838	3,891	4,623	5,599	5,220	4,527	25.0
13a	Closed	1MW	557.06	746	32	3,271	3,074	3,213	4,225	4,671	4,340	535	24.4
14a	Closed	2MW	557.00	746	32	3,526	3,261	3,380	4,382	4,924	4,570	669	24.4
15a	Closed	40%	556.97	746	32	4,147	3,798	3,866	4,661	5,567	5,170	1,784	24.6
16b	Open	60%	556.94	747	31	4,645	4,229	4,275	4,965	6,176	5,760	2,760	24.8
17a	Closed	80%	557.02	746	31	3,806	3,612	3,662	4,424	5,227	4,870	3,883	24.9
18a	Closed	90%	557.07	745	32	2,300	2,445	2,556	3,753	3,747	3,470	4,486	25.1
19a	Closed	1MW	559.82	746	32	576	1,942	2,096	2,752	2,497	2,320	574	24.6
20a	Closed	2MW	559.98	746	32	1,709	2,059	2,186	3,392	3,158	2,930	751	24.5
21a	Closed	40%	560.12	746	33	2,497	2,573	2,732	3,800	3,938	3,640	1,767	24.9
22a	Closed	60%	560.10	746	33	3,770	3,616	3,644	4,368	5,180	4,790	2,745	25.0
23a	Closed	80%	560.09	746	33	2,889	2,922	2,992	3,814	4,257	3,940	3,885	25.1
24a	Closed	90%	560.14	746	33	130	782	1,313	1,632	1,308	1,210	4,481	25.1
27a	Closed	40%	562.75	746	33	906	1,232	1,440	2,414	2,055	1,900	1,755	25.7
28a	Closed	60%	562.93	746	34	3,134	2,982	2,989	3,765	4,362	4,020	2,745	25.9
29a	Closed	80%	563.04	746	34	2,216	2,343	2,450	3,380	3,470	3,200	3,879	25.9
30a	Closed	90%	563.20	746	34	31	27	20	1,015	371	340	4,478	25.9

Table 1 continued: 2002 Main Generator 3 Data

Measured Values												
Run #	Aux Vents Unit 6	Gate Setting %	Tailrace Elev. (feet)	TDG mmHg	TDG %	Calculated TDG %	Calculated PT-PO2	% Sat Nitrogen + Aragon	Tailrace DO mg/L	Tailrace DO % Sat	Intake DO mg/L	Datasheet DO mg/L
1a	Closed	1MW	551.52	845	113	112.8	716	125	7.04	84.4	0.01	6.90
1a	Closed	1MW	551.52						7.07			6.90
2a	Open	2MW	551.61	854	114	114.0	722	126	7.22	86.4	0.01	7.10
2a	Open	2MW	551.61						7.50			7.20
7a	Closed	1MW	553.57	780	104	104.3	673	117	5.76	70.2	0.39	5.75
8a	Closed	2MW	554.18	829	111	111.0	716	125	6.11	74.5	0.05	5.97
9a	Closed	40%	554.18	786	105	105.2	700	122	4.65	56.9	0.05	4.58
10b	Open	60%	554.09	828	111	110.7	731	128	5.22	64.0	0.20	5.04
11a	Closed	80%	554.26	766	103	102.5	693	121	3.90	48.1	0.32	3.84
12a	Closed	90%	554.44	784	105	105.0	714	125	3.72	45.9	0.34	3.61
13a	Closed	1MW	557.06	778	104	104.3	670	117	5.81	71.0	0.04	5.84
14a	Closed	2MW	557.00	780	105	104.6	684	120	5.20	63.6	0.02	5.16
15a	Closed	40%	556.97	806	108	108.0	713	125	5.02	61.6	0.04	4.73
16b	Open	60%	556.94	764	102	102.3	688	120	4.10	50.4	0.24	3.99
17a	Closed	80%	557.02	744	100	99.7	685	120	3.17	39.1	0.35	3.14
18a	Closed	90%	557.07	741	99	99.5	683	120	3.07	38.1	0.40	2.87
19a	Closed	1MW	559.82	756	101	101.3	668	117	4.76	58.4	0.31	4.74
20a	Closed	2MW	559.98	755	101	101.2	670	117	4.60	56.4	0.03	4.64
21a	Closed	40%	560.12	757	101	101.5	689	121	3.63	44.8	0.03	3.64
22a	Closed	60%	560.10	744	100	99.7	684	120	3.21	39.7	0.36	3.14
23a	Closed	80%	560.09	740	99	99.2	686	120	2.88	35.7	0.36	2.77
24a	Closed	90%	560.14	734	98	98.4	691	121	2.32	28.7	0.44	2.10
27a	Closed	40%	562.75	742	99	99.5	676	119	3.49	43.7	1.22	3.30
28a	Closed	60%	562.93	746	100	100.0	682	120	3.39	42.6	0.76	3.61
29a	Closed	80%	563.04	741	99	99.3	677	119	3.37	42.4	1.08	3.19
30a	Closed	90%	563.20	726	97	97.3	679	119	2.46	30.9	1.08	2.36

Table 1 continued: 2002 Main Generator 3 Data

Calculated Values											
Run #	Aux Vents Unit 6	Gate Setting %	Tailrace Elev. (feet)	Net DO Transfer mg/L	O2 in Water lb./min	O2 in Air ¹ lb./min	Air Flow/ Discharge	Oxygen Transfer Efficiency	Aeration Efficiency	Oxygen Transfer Rate (lb/hr)	Predicted OTE
1a	Closed	1MW	551.52	7.03	11.6	93.6	0.231	12%	0.818	700	12%
1a	Closed	1MW	551.52								
2a	Open	2MW	551.61	7.21	18.4	101.0	0.161	18%	0.839	1,100	15%
2a	Open	2MW	551.61								
7a	Closed	1MW	553.57	5.37	10.1	82.4	0.179	12%	0.670	600	14%
8a	Closed	2MW	554.18	6.06	14.8	84.2	0.141	18%	0.726	890	17%
9a	Closed	40%	554.18	4.60	29.6	102.0	0.064	29%	0.551	1,780	28%
10b	Open	60%	554.09	5.02	51.7	103.6	0.041	50%	0.612	3,100	38%
11a	Closed	80%	554.26	3.58	55.1	82.5	0.022	67%	0.443	3,310	59%
12a	Closed	90%	554.44	3.38	62.0	79.8	0.018	78%	0.419	3,720	68%
13a	Closed	1MW	557.06	5.77	9.9	66.1	0.157	15%	0.690	600	15%
14a	Closed	2MW	557.00	5.18	11.8	69.6	0.125	17%	0.618	710	18%
15a	Closed	40%	556.97	4.98	32.3	78.7	0.050	41%	0.596	1,940	34%
16b	Open	60%	556.94	3.86	40.0	88.0	0.035	46%	0.473	2,400	43%
17a	Closed	80%	557.02	2.82	43.5	74.4	0.020	58%	0.350	2,610	63%
18a	Closed	90%	557.07	2.67	49.1	52.8	0.012	93%	0.338	2,950	89%
19a	Closed	1MW	559.82	4.45	8.2	35.3	0.079	23%	0.550	490	25%
20a	Closed	2MW	559.98	4.57	11.3	44.6	0.074	25%	0.546	680	26%
21a	Closed	40%	560.12	3.60	23.3	55.2	0.035	42%	0.430	1,400	43%
22a	Closed	60%	560.10	2.85	29.6	72.7	0.029	41%	0.354	1,770	49%
23a	Closed	80%	560.09	2.52	38.8	59.8	0.016	65%	0.317	2,330	73%
24a	Closed	90%	560.14	1.88	34.3	18.4	0.004	187%	0.239	2,060	182%
27a	Closed	40%	562.75	2.27	14.1	28.8	0.019	49%	0.321	850	64%
28a	Closed	60%	562.93	2.63	27.2	60.8	0.024	45%	0.349	1,630	55%
29a	Closed	80%	563.04	2.29	35.2	48.4	0.013	73%	0.317	2,110	84%
30a	Closed	90%	563.20	1.38	25.0	5.1	0.001	487%	0.191	1,500	

Table 2: 2002 Main Generator 6 Data - Auxiliary Vents Open

Measured Values												
Run #	Gate Setting %	Tailrace Elev. (feet)	Baro Press. (mmHg)	Air Temp (°C)	Air Flow (cfm)	Std Air Flow (scfm)	Discharge (cfs)	Tailrace Water Temp (°C)	Tailrace DO mg/L	Tailrace DO % Sat	Intake DO mg/L	Datasheet DO mg/L
1b	1MW	551.54	745	28	8,514	8,000	450	23.6	7.26	87.6	0.12	7.20
2b	2MW	551.57	747	28	8,856	8,340	614	23.7	7.18	86.5	0.12	7.10
7b	1MW	553.66	746	28	6,322	5,950	491	24.4	5.82	71.2	0.14	5.70
8b	2MW	554.05	747	28	6,569	6,190	614	24.2	6.13	74.6	0.14	5.90
9b	40%	554.09	747	28	5,741	5,410	1,758	24.5	4.54	55.5	0.22	4.50
10b	60%	554.09	747	28	4,868	4,580	2,779	24.7	3.76	46.2	0.24	3.60
11b	80%	554.47	746	28	1,748	1,640	3,947	24.9	2.38	29.4	0.32	2.40
13b	1MW	557.04	746	30	5,259	4,910	540	24.5	4.32	52.9	0.12	4.30
14b	2MW	557.00	745	30	5,644	5,270	675	24.4	5.06	62.0	0.12	5.00
15b	40%	556.94	745	30	4,267	3,980	1,800	24.6	4.22	51.9	0.24	4.00
16b	60%	556.94	746	30	3,408	3,180	2,796	24.8	3.55	43.7	0.24	3.50
17b	80%	557.03	745	30	469	440	3,929	25.0	2.02	25.0	0.37	1.90
18b	90%	557.06	744	30	20	20	4,333	25.0	1.93	23.9	0.38	1.80
19b	1MW	559.87	745	30	4,786	4,470	582	24.8	5.39	66.5	0.51	5.00
20b	2MW	559.95	745	30	5,567	5,190	717	25.0	3.67	45.4	0.15	3.50
21b	40%	560.17	745	30	2,920	2,720	1,792	25.1	3.94	48.9	0.23	3.80
22b	60%	560.08	745	30	2,577	2,400	2,780	25.3	3.13	39.0	0.23	2.90
23b	80%	560.11	745	30	268	250	3,867	25.5	2.01	25.1	0.54	1.90
24b	90%	560.11	745	30	0	0	4,242	25.5	2.06	25.7	0.54	1.90
27b	40%	562.75	747	31	1,541	1,440	1,765	25.8	3.52	44.1	0.65	3.40
28b	60%	562.78	746	31	1,330	1,240	2,747	26.0	3.43	43.2	0.65	3.40
29b	80%	563.03	745	31	125	120	3,795	26.2	2.57	32.5	0.92	2.50
30b	90%	563.13	745	31	0	0	4,155	26.1	2.54	32.1	0.92	2.40

Table 2 continued: 2002 Main Generator 6 Data - Auxiliary Vents Open

Calculated Values										
Run #	Gate Setting %	Tailrace Elev. (feet)	Net DO transfer mg/L	O2 in Water lb./min	O2 in Air ¹ lb./min	Air Flow/ Discharge	Oxygen Transfer Efficiency	Aeration Efficiency	Oxygen Transfer Rate (lb/hr)	Predicted OTE
1b	1MW	551.54	7.14	12.0	125.8	0.296	10%	0.842	720	8%
2b	2MW	551.57	7.06	16.4	131.1	0.224	13%	0.833	980	10%
7b	1MW	553.66	5.68	10.4	93.6	0.202	11%	0.688	630	10%
8b	2MW	554.05	5.99	13.9	97.3	0.166	14%	0.725	830	12%
9b	40%	554.09	4.32	29.8	85.1	0.049	35%	0.528	1,790	32%
10b	60%	554.09	3.52	39.8	72.0	0.025	55%	0.431	2,390	55%
11b	80%	554.47	2.06	31.2	25.8	0.007	121%	0.255	1,870	157%
13b	1MW	557.04	4.20	7.6	77.2	0.170	10%	0.507	450	12%
14b	2MW	557.00	4.94	11.3	82.9	0.144	14%	0.597	680	14%
15b	40%	556.94	3.98	27.1	62.6	0.036	43%	0.488	1,630	41%
16b	60%	556.94	3.31	36.8	50.0	0.018	74%	0.406	2,210	72%
17b	80%	557.03	1.65	24.7	6.9	0.002	356%	0.205	1,480	442%
18b	90%	557.06	1.55	25.3	0.3	0.000	8030%	0.196	1,520	5558%
19b	1MW	559.87	4.88	9.5	70.3	0.143	14%	0.619	570	14%
20b	2MW	559.95	3.52	9.2	81.6	0.124	11%	0.427	550	15%
21b	40%	560.17	3.71	24.9	42.8	0.025	58%	0.460	1,490	55%
22b	60%	560.08	2.90	31.7	37.7	0.014	84%	0.359	1,900	89%
23b	80%	560.11	1.47	21.6	3.9	0.001	550%	0.189	1,300	686%
24b	90%	560.11	1.52	24.4	0.0	0.000		0.196	1,470	
27b	40%	562.75	2.87	18.9	22.6	0.014	84%	0.375	1,140	90%
28b	60%	562.78	2.78	29.9	19.5	0.007	153%	0.373	1,790	149%
29b	80%	563.03	1.65	24.0	1.9	0.001	1271%	0.230	1,440	1218%
30b	90%	563.13	1.62	25.7	0.0	0.000		0.226	1,540	

Table 3: 2002 Main Generator 6 Data - Auxiliary Vents Closed

Measured Values												
Run #	Gate Setting %	Tailrace Elev. (feet)	Baro Press. (mmHg)	Air Temp (°C)	Air Flow (cfm)	Std Air Flow (scfm)	Discharge (cfs)	Tailrace Water Temp (°C)	Tailrace DO mg/L	Tailrace DO % Sat	Intake DO mg/L	Datasheet DO mg/L
1a	1MW	551.54	745	28	4,234	3,980	450	23.7	6.82	82.4	0.12	6.80
2a	2MW	551.57	749	28	4,252	4,020	614	23.7	6.86	82.4	0.12	6.90
7a	1MW	553.66	747	28	4,282	4,030	491	24.5	4.86	59.5	0.17	4.70
8a	2MW	554.05	746	28	4,300	4,040	614	24.2	5.77	70.3	0.14	5.70
9a	40%	554.09	746	28	3,040	2,860	1,758	24.4	4.21	51.5	0.22	4.00
10a	60%	554.09	746	28	2,890	2,720	2,779	24.7	3.37	41.4	0.24	3.40
11a	80%	554.47	746	28	1,093	1,030	3,947	24.9	2.23	27.5	0.24	2.15
13a	1MW	557.04	746	31	3,202	2,980	540	24.5	4.41	54.0	0.12	4.30
14a	2MW	557.00	745	30	3,578	3,340	675	24.5	4.20	51.5	0.12	4.20
15a	40%	556.94	745	30	2,206	2,060	1,800	24.7	3.90	48.0	0.12	3.70
16a	60%	556.94	746	30	2,701	2,520	2,796	24.8	3.11	38.3	0.33	2.80
17a	80%	557.03	745	30	0	0	3,929	25.0	2.08	25.8	0.37	1.90
18a	90%	557.06	744	30	0	0	4,333	25.0	1.99	24.7	0.38	1.90
19a	1MW	559.87	744	30	3,370	3,140	582	24.8	4.60	56.8	0.51	4.60
20a	2MW	559.95	745	30	3,504	3,270	761	24.9	3.94	48.7	0.17	3.70
21a	40%	560.17	745	30	2,865	2,670	1,792	25.2	3.01	37.4	0.23	2.80
22a	60%	560.08	746	30	2,115	1,980	2,780	25.3	3.05	37.9	0.46	2.80
23a	80%	560.11	745	30	0	0	3,867	25.4	1.97	24.6	0.46	1.90
24a	90%	560.11	745	30	0	0	4,242	25.6	2.02	25.3	0.54	1.90
27a	40%	562.75	746	31	1,700	1,580	1,765	25.8	3.61	45.3	1.01	3.50
28a	60%	562.78	746	31	1,615	1,500	2,747	26.0	3.28	41.3	0.65	3.10
29a	80%	563.03	746	31	0	0	3,795	26.1	2.79	35.2	0.65	2.60
30a	90%	563.13	745	31	0	0	4,155	26.1	2.40	30.3	0.92	2.40

Table 3 continued: 2002 Main Generator 6 Data - Auxiliary Vents Closed

Calculated Values									
Run #	Gate Setting %	Tailrace Elev. (feet)	Net DO transfer mg/L	O2 in Water lb./min	O2 in Air ¹ lb./min	Air Flow/ Discharge	Oxygen Transfer Efficiency	Aeration Efficiency	Oxygen Transfer Rate (lb/hr)
1a	1MW	551.54	6.70	11.3	62.6	0.147	18%	0.790	680
2a	2MW	551.57	6.74	15.7	63.2	0.108	25%	0.795	940
7a	1MW	553.66	4.69	8.6	63.4	0.137	14%	0.570	520
8a	2MW	554.05	5.63	13.1	63.5	0.109	21%	0.682	780
9a	40%	554.09	3.99	27.5	45.0	0.026	61%	0.488	1,650
10a	60%	554.09	3.13	35.4	42.8	0.015	83%	0.384	2,120
11a	80%	554.47	1.99	30.1	16.2	0.004	186%	0.244	1,810
13a	1MW	557.04	4.29	7.7	46.9	0.103	16%	0.518	460
14a	2MW	557.00	4.08	9.3	52.5	0.091	18%	0.493	560
15a	40%	556.94	3.78	25.8	32.4	0.019	80%	0.457	1,550
16a	60%	556.94	2.78	30.9	39.6	0.014	78%	0.344	1,860
17a	80%	557.03	1.71	25.6	0.0	0.000		0.213	1,530
18a	90%	557.06	1.61	26.2	0.0	0.000		0.203	1,570
19a	1MW	559.87	4.09	8.0	49.4	0.101	16%	0.518	480
20a	2MW	559.95	3.77	9.9	51.4	0.078	19%	0.458	590
21a	40%	560.17	2.78	18.6	42.0	0.025	44%	0.344	1,120
22a	60%	560.08	2.59	28.3	31.1	0.011	91%	0.330	1,700
23a	80%	560.11	1.51	22.2	0.0	0.000		0.193	1,330
24a	90%	560.11	1.48	23.8	0.0	0.000		0.191	1,430
27a	40%	562.75	2.60	17.1	24.8	0.015	69%	0.357	1,030
28a	60%	562.78	2.63	28.3	23.6	0.009	120%	0.353	1,700
29a	80%	563.03	2.14	31.1	0.0	0.000		0.287	1,870
30a	90%	563.13	1.48	23.4	0.0	0.000		0.206	1,410

Table 4: 2003 Main Generator 3 Data

Measured Values													
Run #	Gate Setting %	Unit Load MW	Tailrace Elev. (feet)	Baro Press. (mmHg)	Tailrace Air Temp (°C)	Relative Humidity %	Turbine Barrel Air Temp (°C)	Air Flow (cfs)	Standard Air Flow (scfm)	Discharge (cfs)	Tailrace Water Temp (°C)	Rounded Water Temp (°C)	Tailrace Sp. Cond. uS/cm
1	11%	1	551.63	754	19	63	26	128	7,200	492	18.3	18.3	312
2	12%	1	554.16	753	26	55	28	110	6,000	537	19.2	19.2	312
3	40%	10	553.93	753	26	54	28	139	7,800	1,788	19.2	19.2	312
4	60%	16	554.09	753	26	53	28	145	8,400	2,772	19.4	19.4	313
5	80%	24	554.25	753	26	53	29	130	7,200	3,909	19.9	19.9	312
6	90%	31	554.31	753	27	54	29	159	9,000	4,527	20.1	20.1	312
7	11%	1	556.60	752	32	45	32	96	5,400	490	19.6	19.6	312
8	40%	9	556.83	752	33	45	32	115	6,600	1,784	19.6	19.6	312
9	40%	9	557.01	752	34	47				1,784			
10	60%	16	557.03	752	37	41				2,760			
11	60%	16	556.94	752	37	44	35	125	7,200	2,760	20.0	20.0	311
12	80%	24	556.97	752	36	45	35	107	6,000	3,883	20.3	20.3	310
13	18%	3	557.23	752	37	44							
14	Float	0	557.14	752	37	45							
15	90%	31	557.14	752	39	41	37	138	7,800	4,486	20.4	20.4	311
16	12%	1	559.88	752	36	43	36	42	2,400	530	19.8	19.8	312
17	40%	9	560.02	751	35	48	36	76	4,200	1,767	20.0	20.0	312
18	40%	7	560.20	751	34	46				1,767			
19	40%	7	560.22	751	33	45				1,767			
20	60%	16	560.22	752	31	48	32	96	5,400	2,745	20.1	20.1	312
21	80%	24	560.21	752	30	49	32	89	4,800	3,885	20.7	20.7	311
22	80%	29	560.21	752	31	49				3,885			
23	80%	30	560.33	751	33	46				3,885			
24	90%	30	560.30	751	33	46	33	98	5,400	4,481	21.3	21.3	310
25	40%	7	562.83	751	34	48	26	41	2,400	1,755	20.5	20.5	312
26	40%	6	562.91	751	33	48				1,755			
27	40%	6	563.00	751	31	50				1,755			
28	60%	15	563.18	751	32	49	27	78	4,200	2,745	20.3	20.3	312
29	80%	24	563.30	751	32	49	26	75	4,200	3,879	20.8	20.8	311
30	67%	20	563.43	751	31	50							
31	55%	13	563.15	751	31	50				2,479			
32	90%	30	563.09	751	31	50	26	88	4,800	4,478	20.7	20.7	311

Estimated Values

Table 4 continued: 2003 Main Generator 3 Data

Measured Values													
Run #	Gate Setting %	Unit Load MW	Tailrace Elev. (feet)	TDG mmHg	Measured TDG % Sat	Calculated TDG % Sat	Recorded PT-pO2 mmHg	Calculated P _T -pO ₂ mmHg	Calculated % Sat NO ₂ + Ar	Tailrace DO mg/L	Recorded Tailrace DO % Sat	Calculated Tailrace DO % Sat	Intake DO mg/L
1	11%	1	551.63	867	115	115.0	717	737	126	7.82	83.1	83.9	0.00
2	12%	1	554.16	835	110	110.9	711	727	125	6.40	69.2	70.0	0.00
3	40%	10	553.93	866	115	115.0		750	129	6.87			0.00
4	60%	16	554.09	840	111	111.6	719	737	128	6.08	66.2	66.8	0.22
5	80%	24	554.25	809	107	107.4	700	718	124	5.31	58.3	58.9	0.32
6	90%	31	554.31	808	107	107.3	705	723	124	4.98	54.8	55.5	0.31
7	11%	1	556.60	831	110	110.5	723	735	127	5.62	61.4	62.1	0.01
8	40%	9	556.83	840	111	111.7	731	748	129	5.44	59.4	60.1	0.12
9	40%	9	557.01										
10	60%	16	557.03										
11	60%	16	556.94	843	112	112.1	726	747	129	5.62	61.9	62.6	0.19
12	80%	24	556.97	801	106	106.5	699	718	124	4.81	53.3	53.9	0.33
13	18%	3	557.23										
14	Float	0	557.14										
15	90%	31	557.14	786	104	104.5	681	698	120	5.11	56.6	57.4	0.24
16	12%	1	559.88	848	112	112.8	747	753	130	5.55	60.9	61.6	0.00
17	40%	9	560.02	845	112	112.5	754	754	130	5.32	58.5	59.3	0.03
18	40%	7	560.20										
19	40%	7	560.22										
20	60%	16	560.22	777	103	103.3	712	712	123	3.79	41.9	42.3	0.19
21	80%	24	560.21	756	100	100.5	681	684	118	4.13	46.1	46.6	0.39
22	80%	29	560.21										
23	80%	30	560.33										
24	90%	30	560.30	750	99	99.9	680	678	117	4.08	46.2	46.7	0.54
25	40%	7	562.83	791	105	105.3	726	724	125	3.88	43.1	43.7	0.04
26	40%	6	562.91										
27	40%	6	563.00										
28	60%	15	563.18	808	107	107.6	740	732	126	4.42	48.9	49.6	0.14
29	80%	24	563.30	739	98	98.4	678	685	118	3.09	34.6	35.0	0.25
30	67%	20	563.43										
31	55%	13	563.15										
32	90%	30	563.09	747	99	99.5	694	691	119	3.25	36.3	36.8	0.30

Table 4 continued: 2003 Main Generator 3 Data

Calculated Values											
Run #	Gate Setting %	Unit Load MW	Tailrace Elev. (feet)	Aeration Efficiency	Net DO Transfer mg/L	O2 in Water lb./min	O2 in Air lb./min	Air Flow/ Discharge	Oxygen Transfer Efficiency	Oxygen Transfer Rate (lb/hr)	OTR/ Air Discharge
1	11%	1	551.63	0.84	7.82	10.3	111.5	0.341	9%	620	0.07
2	12%	1	554.16	0.70	6.40	9.5	92.5	0.253	10%	570	0.07
3	40%	10	553.93		6.87	43.5	120.2	0.077	36%	2,610	0.06
4	60%	16	554.09	0.66	5.86	57.9	129.4	0.053	45%	3,470	0.05
5	80%	24	554.25	0.57	4.99	71.0	110.7	0.032	64%	4,260	0.05
6	90%	31	554.31	0.54	4.67	79.0	138.3	0.033	57%	4,740	0.03
7	11%	1	556.60	0.62	5.61	6.5	82.2	0.289	8%	390	0.07
8	40%	9	556.83	0.60	5.32	33.2	100.5	0.066	33%	1,990	0.05
9	40%	9	557.01								
10	60%	16	557.03								
11	60%	16	556.94	0.62	5.43	53.3	108.5	0.046	49%	3,200	0.05
12	80%	24	556.97	0.52	4.48	63.5	90.4	0.026	70%	3,810	0.05
13	18%	3	557.23								
14	Float	0	557.14								
15	90%	31	557.14	0.56	4.87	82.5	116.7	0.029	71%	4,950	0.04
16	12%	1	559.88	0.62	5.55	6.9	36.0	0.120	19%	420	0.15
17	40%	9	560.02	0.59	5.29	33.1	63.1	0.042	52%	1,980	0.08
18	40%	7	560.20								
19	40%	7	560.22								
20	60%	16	560.22	0.41	3.60	35.4	82.2	0.034	43%	2,120	0.04
21	80%	24	560.21	0.44	3.74	53.2	73.1	0.021	73%	3,190	0.05
22	80%	29	560.21								
23	80%	30	560.33								
24	90%	30	560.30	0.43	3.54	59.6	81.9	0.020	73%	3,580	0.04
25	40%	7	562.83	0.43	3.84	22.7	37.2	0.025	61%	1,360	0.10
26	40%	6	562.91								
27	40%	6	563.00								
28	60%	15	563.18	0.49	4.28	41.7	64.9	0.027	64%	2,500	0.07
29	80%	24	563.30	0.33	2.84	40.3	65.1	0.018	62%	2,420	0.04
30	67%	20	563.43								
31	55%	13	563.15								
32	90%	30	563.09	0.35	2.95	49.4	74.3	0.018	67%	2,970	0.04

Table 5: 2003 Main Generator 6 Data

Measured Values														
Run #	Gate Setting %	Unit Load MW	Aux Vents	Tailrace Elev. (feet)	Baro Press. (mmHg)	Tailrace Air Temp (°C)	Relative Humidity %	Turbine Barrel Air Temp (°C)	Air Flow (cfs)	Standard Air Flow (scfm)	Discharge (cfs)	Tailrace Water Temp (°C)	Rounded Water Temp (°C)	Tailrace Sp. Cond. uS/cm
1	12%	1	Closed	551.63	754	20	54	25	5,125	4,920	491	18.0	18.0	305
2	12%	1	Closed	554.16	753		41	27	4,636	4,420	491	19.3	19.3	306
3	40%	11	Closed	553.93	753		39	27	4,232	4,030	1,758	19.2	19.2	303
4	60%	20	Closed	554.09	753		40	27	3,736	3,560	2,779	19.5	19.5	302
5	80%	29	Closed	554.25	753		40	27	3,465	3,300	3,947	20.0	20.0	303
6	60%	20	Closed	554.31	753		39	27	4,057	3,860	2,779	19.7	19.7	302
7	12%	1	Closed	556.60	752		52	29	4,031	3,810	540	19.4	19.4	302
8	40%	11	Closed	556.83	752		40	30	3,691	3,480	1,800	19.6	19.6	304
9	40%	11	Open	557.01	752		38	33	7,134	6,650	1,800	19.4	19.4	303
10	60%	18	Open	557.03	752		40	33	5,331	4,970	2,796	19.7	19.7	303
11	60%	19	Closed	556.94	752		44	33	3,364	3,140	2,796	19.7	19.7	303
12	80%	28	Closed	556.97	752		51	33	2,706	2,520	3,929	20.0	20.0	303
13	80%	28	Open	557.23	752		51	34	5,563	5,170	3,929	20.1	20.1	302
14	90%	30	Open	557.14	752		51	33	3,528	3,290	4,333	20.3	20.3	302
15	90%	30	Closed	557.14	752		49	35	1,814	1,680	4,333	20.3	20.3	302
16	12%	1	Closed	559.88	752		51	34	3,600	3,350	537	20.4	20.4	305
17	40%	10	Closed	560.02	751		50	33	3,609	3,360	1,792	20.3	20.3	303
18	40%	10	Open	560.20	751		51	33	4,800	4,470	1,792	20.1	20.1	303
19	60%	18	Open	560.22	751		51	32	4,890	4,570	2,780	20.5	20.5	303
20	60%	18	Closed	560.22	752		51	29	2,894	2,730	2,780	20.4	20.4	303
21	80%	27	Closed	560.21	752		52	30	1,736	1,630	3,867	21.1	21.1	302
22	80%	27	Open	560.21	752		52	30	3,514	3,310	3,867	20.9	20.9	301
23	90%	29	Open	560.33	751			30	1,564	1,470	4,242	20.9	20.9	302
24	90%	28	Closed	560.30	751		49	30	733	690	4,242	21.0	21.0	302
25	40%	10	Closed	562.83	751		49	31	2,421	2,270	1,765	20.6	20.6	301
26	40%	10	Open	562.91	751		50	31	2,613	2,450	1,765	20.3	20.3	303
27	60%	18	Open	563.00	751		51	31	2,878	2,700	2,747	20.9	20.9	301
28	60%	18	Closed	563.18	751		51	32	1,979	1,850	2,747	21.1	21.1	301
29	80%	26	Closed	563.30	751		51	31	656	620	3,795	21.5	21.5	302
30	80%	26	Open	563.43	751		51	31	1,248	1,170	3,795	21.4	21.4	301
31	90%	28	Open	563.15	751		52	31	544	510	4,155	21.2	21.2	302
32	90%	28	Closed	563.09	751		51	31	124	120	4,155	21.2	21.2	302

Estimated Values

Table 5 continued: 2003 Main Generator 6 Data

Measured Values														
Run #	Gate Setting %	Unit Load MW	Aux Vents	Tailrace Elev. (feet)	TDG mmHg	Measured TDG % Sat	Calculated TDG % Sat	Recorded P _T -pO ₂ mmHg	Calculated P _T -pO ₂ mmHg	Calculated % Sat NO ₂ + Ar	Tailrace DO mg/L	Recorded Tailrace DO % Sat	Calculated Tailrace DO % Sat	Intake DO mg/L
1	12%	1	Closed	551.63	895	118	118.7	744	761	130	8.14	85.9	86.8	0.00
2	12%	1	Closed	554.16	849	112	112.7	725	738	127	6.54	71.0	71.7	0.00
3	40%	11	Closed	553.93	802	106	106.5	715	724	124	4.61	49.9	50.5	0.05
4	60%	20	Closed	554.09	765	101	101.6	691	700	120	3.83	41.7	42.2	0.12
5	80%	29	Closed	554.25	725	96	96.3	665	673	116	3.04	33.5	33.8	0.16
6	60%	20	Closed	554.31	753	100	100.0	680	691	119	3.66	40.1	40.5	0.19
7	12%	1	Closed	556.60	856	113	113.8	735	753	131	6.06	65.9	66.7	0.00
8	40%	11	Closed	556.83	810	107	107.7	720	737	127	4.27	46.7	47.2	0.05
9	40%	11	Open	557.01	822	109	109.3	723	740	128	4.87	53.0	53.6	0.04
10	60%	18	Open	557.03	787	104	104.7		718	124	4.06	44.4	44.9	0.20
11	60%	19	Closed	556.94	755	100	100.4	676	697	120	3.38	37.0	37.4	0.16
12	80%	28	Closed	556.97	723	95	96.1	657	674	116	2.84	31.3	31.6	0.17
13	80%	28	Open	557.23	750	99	99.7	671	688	119	3.59	39.6	40.1	0.19
14	90%	30	Open	557.14	716	94	95.2	651	670	116	2.65	29.4	29.7	0.13
15	90%	30	Closed	557.14	697	92	92.7	642	655	113	2.41	26.7	27.0	0.11
16	12%	1	Closed	559.88	794	105	105.6	698	717	124	4.48	49.8	50.3	0.00
17	40%	10	Closed	560.02	802	106	106.8	729	728	126	4.28	47.4	48.0	0.09
18	40%	10	Open	560.20	837	111	111.5	739	754	130	4.83	53.3	54.0	0.08
19	60%	18	Open	560.22	759	100	101.1	678	696	120	3.65	40.5	41.1	0.13
20	60%	18	Closed	560.22	746	99	99.2	672	691	119	3.21	35.7	36.0	0.13
21	80%	27	Closed	560.21	697	92	92.7	633	653	113	2.49	28.2	28.3	0.19
22	80%	27	Open	560.21	718	95	95.5	649	666	115	2.97	33.3	33.7	0.23
23	90%	29	Open	560.33	695	92	92.5	631	659	114	2.09	23.5	23.7	0.23
24	90%	28	Closed	560.30	679	90	90.4		644	111	2.02	22.7	23.0	0.32
25	40%	10	Closed	562.83	769	102	102.4	695	708	122	3.51	39.1	39.6	0.08
26	40%	10	Open	562.91	773	102	102.9	697	715	123	3.35	37.1	37.6	0.09
27	60%	18	Open	563.00	738	98	98.3	664	683	118	3.14	35.2	35.7	0.05
28	60%	18	Closed	563.18	724	96	96.4	652	673	116	2.94	33.1	33.5	0.28
29	80%	26	Closed	563.30	682	90	90.8	622	641	111	2.32	26.3	26.7	0.32
30	80%	26	Open	563.43	678	90	90.3	616	636	110	2.38	27.0	27.3	0.33
31	90%	28	Open	563.15	661	87	88.0	606	629	109	1.85	20.9	21.1	0.29
32	90%	28	Closed	563.09	654	86	87.1	605	624	108	1.74	19.7	19.9	0.31

Table 5 continued: 2003 Main Generator 6 Data

Calculated Values											
Run #	Gate Setting %	Unit Load MW	Aux Vents	Aeration Efficiency	Net DO Transfer mg/L	O2 in Water lb./min	O2 in Air lb./min	Air Flow/ Discharge	Oxygen Transfer Efficiency	Oxygen Transfer Rate (lb/hr)	OTR/ Air Discharge
1	12%	1	Closed	0.871	8.14	17.3	76.4	0.144	23%	1,040	0.11
2	12%	1	Closed	0.719	6.54	13.4	68.3	0.135	20%	800	0.10
3	40%	11	Closed	0.503	4.56	34.0	62.3	0.034	55%	2,040	0.07
4	60%	20	Closed	0.416	3.71	42.3	55.0	0.020	77%	2,540	0.07
5	80%	29	Closed	0.328	2.88	44.9	51.0	0.013	88%	2,690	0.06
6	60%	20	Closed	0.394	3.47	39.5	59.6	0.021	66%	2,370	0.06
7	12%	1	Closed	0.667	6.06	13.0	58.6	0.111	22%	780	0.10
8	40%	11	Closed	0.470	4.22	30.6	53.4	0.030	57%	1,830	0.08
9	40%	11	Open	0.535	4.83	34.7	100.9	0.058	34%	2,080	0.05
10	60%	18	Open	0.437	3.86	42.7	75.4	0.028	57%	2,560	0.05
11	60%	19	Closed	0.364	3.22	36.2	47.6	0.017	76%	2,170	0.07
12	80%	28	Closed	0.304	2.67	41.1	38.2	0.010	107%	2,460	0.07
13	80%	28	Open	0.389	3.40	52.0	78.2	0.021	67%	3,120	0.04
14	90%	30	Open	0.287	2.52	41.5	49.9	0.012	83%	2,490	0.05
15	90%	30	Closed	0.262	2.30	37.9	25.3	0.006	150%	2,270	0.09
16	12%	1	Closed	0.505	4.48	10.2	50.7	0.092	20%	610	0.09
17	40%	10	Closed	0.475	4.19	29.5	51.0	0.030	58%	1,770	0.08
18	40%	10	Open	0.536	4.75	33.4	67.8	0.040	49%	2,000	0.07
19	60%	18	Open	0.402	3.52	38.5	69.6	0.026	55%	2,310	0.05
20	60%	18	Closed	0.352	3.08	33.9	42.0	0.015	81%	2,040	0.07
21	80%	27	Closed	0.269	2.30	34.7	25.0	0.007	139%	2,080	0.09
22	80%	27	Open	0.320	2.74	41.5	50.7	0.014	82%	2,490	0.05
23	90%	29	Open	0.217	1.86	30.4	22.5	0.006	135%	1,820	0.08
24	90%	28	Closed	0.201	1.70	27.6	10.6	0.003	261%	1,660	0.16
25	40%	10	Closed	0.392	3.43	23.6	34.7	0.021	68%	1,410	0.10
26	40%	10	Open	0.370	3.26	22.3	37.4	0.022	60%	1,340	0.09
27	60%	18	Open	0.354	3.09	33.5	41.3	0.016	81%	2,010	0.07
28	60%	18	Closed	0.314	2.66	29.0	28.2	0.011	103%	1,740	0.09
29	80%	26	Closed	0.239	2.00	29.9	9.5	0.003	316%	1,800	0.21
30	80%	26	Open	0.245	2.05	30.6	17.9	0.005	171%	1,830	0.11
31	90%	28	Open	0.185	1.56	25.0	7.8	0.002	321%	1,500	0.20
32	90%	28	Closed	0.170	1.43	23.0	1.8	0.000	1255%	1,380	0.78

Table 6: 2005 Main Generator 6 Data

Measured Values																			
Run #	Gate Setting (%)	Unit Load (MW)	Draft Tube Vents	New Main Vents	Tailrace Elev. (feet)	Lake Elevation (feet)	Tailrace Baro Press. (mmHg)	Relative Humidity (%)	Turbine Barrel Air Temp (°C)	Turbine Barrel Baro Pressure (mmHg)	Original Main Vent Air Flows (cfm)	Original Main Vent Standard Air Flows (scfm)	New Main Vent Air Flows (cfm)	New Main Vent Standard Air Flows (scfm)	Draft Tube Temp (°C)	Draft Tube Baro Pressure (mmHg)	Draft Tube Air Flow (cfm)	Standard Draft Tube Air Flow (scfm)	Total Stdnd Air Flow (scfm)
1	10%	1	Open	Closed	552.5	659.1	751	76	29	754	21.7	20	38	40	24	753	7,144	6,880	6,940
2	10%	1	Open	Open	552.5	659.1	750	63	29	754	14.1	10	4,198	3,980	24	753	3,644	3,500	7,490
3	10%	1	Closed	Open	552.4	659.2	751	50	29	754	18.9	20	7,901	7,500	24	753	8	10	7,530
4	20%	3	Closed	Open	552.4	659.2	750	47	29	754	21.0	20	8,629	8,190	23	754	7	10	8,220
5	20%	3	Open	Closed	552.4	659.2	750	45	29	754	36.3	30	38	40	24	754	8,732	8,420	8,490
6	30%	7	Open	Closed	552.4	659.2	750	41	29	755	42.8	40	38	40	24	754	10,038	9,660	9,740
7	30%	7	Closed	Open	552.4	659.2	750	39	29	754	20.1	20	8,690	8,230	24	754	7	10	8,260
8	40%	11	Closed	Open	552.4	659.2	750	42	29	754	20.7	20	8,389	7,950	24	754	7	10	7,980
9	40%	11	Open	Closed	552.4	659.2	750	38	29	754	47.6	50	39	40	24	754	10,694	10,290	10,380
10	50%	15	Open	Closed	552.4	659.2	750	38	29	755	50.4	50	39	40	25	754	11,809	11,340	11,430
11	50%	15	Closed	Open	552.5	659.2	750	40	29	754	19.8	20	6,624	6,270	24	754	7	10	6,300
12	60%	19	Closed	Open	552.6	659.2	750	41	29	754	19.9	20	6,043	5,720	23	754	8	10	5,750
13	60%	19	Open	Closed	552.7	659.2	750	38	30	754	52.2	50	39	40	25	753	13,190	12,670	12,760
14	70%	22	Open	Closed	552.8	659.2	750	52	30	754	50.1	50	39	40	25	754	12,798	12,280	12,370
15	70%	22	Closed	Open	553.0	659.2	750	48	30	754	23.4	20	6,585	6,220	24	754	7	10	6,250
16	80%	25	Closed	Open	553.1	659.2	750	50	30	754	24.4	20	6,816	6,440	24	753	8	10	6,470
17	80%	29	Open	Closed	553.2	659.2	750	50	30	754	55.3	50	39	40	25	753	11,512	11,060	11,150
18	90%	29	Open	Closed	553.3	659.2	750	50	30	755	48.0	50	39	40	25	753	11,139	10,690	10,780
19	90%	29	Closed	Open	553.4	659.2	750	42	30	754	21.7	20	5,358	5,050	24	754	8	10	5,080
20	90%	31	Closed	Closed	553.5	659.2	750	47	30	754	58.3	60	39	40	24	754	7	10	110
21	40%	15	Closed	Closed	553.5	659.2	749	42	31	754	65.2	60	46	40	24	753	7	10	110
1	40%	11	Open	Closed	556.4	659.1	742	48	35	747	58.8	50	45	40	25	747	4,923	4,690	4,780
2	40%	10	Open	Open	556.4	659.1	742	46	35	747	17.7	20	5,081	4,680	25	747	3,871	3,680	8,380
3	40%	11	Closed	Open	556.3	659.1	742	46	35	747	19.0	20	6,263	5,770	25	747	8	10	5,800
4	60%	19	Closed	Open	556.2	659.1	742	46	35	747	19.7	20	4,764	4,390	23	747	8	10	4,420
5	60%	18	Open	Open	556.2	659.1	742	44	35	747	19.0	20	2,944	2,710	25	747	8,160	7,770	10,500
6	60%	19	Open	Closed	556.2	659.1	742	44	35	747	54.1	50	43	40	26	747	9,857	9,350	9,440
7	85%	29	Open	Closed	556.2	659.1	742	44	35	747	43.6	40	42	40	26	747	8,029	7,600	7,680
8	85%	29	Open	Open	556.3	659.1	742	45	35	747	20.3	20	822	760	26	747	7,820	7,400	8,180
9	85%	30	Closed	Open	556.4	659.1	741	44	35	747	20.9	20	2,657	2,440	25	747	13	10	2,470
10	40%	10	Open	Closed	560.2	659.0	741	42	36	746	58.5	50	44	40	25	746	1,052	1,000	1,090
11	40%	10	Open	Open	560.3	659.1	741	45	36	746	17.0	20	3,161	2,900	25	746	1,136	1,080	4,000
12	40%	10	Closed	Open	560.2	659.0	741	45	36	747	17.8	20	3,666	3,360	24	746	8	10	3,390
13	60%	19	Closed	Open	560.2	659.0	741	45	36	746	18.9	20	3,465	3,180	23	746	8	10	3,210
14	60%	18	Open	Open	560.2	659.0	741	45	36	746	19.0	20	2,493	2,280	25	746	4,197	3,990	6,290
15	60%	20	Open	Closed	560.3	659.0	741	44	36	746	59.2	50	45	40	25	746	3,223	3,070	3,160
16	85%	28	Open	Closed	560.2	659.0	741	46	36	746	35.4	30	42	40	27	746	3,404	3,220	3,290
17	85%	28	Open	Open	560.0	659.0	741	47	36	746	21.5	20	272	250	27	746	3,274	3,090	3,360
18	85%	29	Closed	Open	560.0	659.0	741	49	36	746	20.1	20	632	580	26	747	12	10	610
19	40%	10	Open	Open	563.0	658.9	742	50	35	747	16.9	20	2,428	2,230	25	747	2,545	2,420	4,670
20	40%	10	Open	Closed	564.0	658.9	743	51	35	747	58.1	50	45	40	25	747	0	0	90
21	40%	10	Closed	Open	563.1	658.9	743		35	747	16.8	20	2,382	2,190	25	747	26	20	2,230
22	60%	18	Closed	Open	563.1	659.0	743	55	34	748	18.9	20	2,746	2,540	25	748	26	20	2,580
23	60%	18	Open	Open	563.1	659.0	744	54	34	748	18.8	20	2,429	2,240	26	749	1,820	1,730	3,990
24	60%	19	Open	Closed	563.1	659.0	744	55	36	749	64.2	60	44	40	25	748	0	0	100
25	85%	27	Open	Closed	563.2	659.0	744	54	35	749	29.4	30	41	40	25	748	1,239	1,180	1,250
26	85%	28	Open	Open	563.1	659.1	744	56	35	749	21.5	20	153	140	26	749	1,438	1,370	1,530
27	85%	28	Closed	Open	563.1	659.0	744	56	35	749	21.3	20	144	130	26	749	24	20	170
28	85%	29	Closed	Closed	563.3	659.0	742	49	35	747	21.4	20	140	130	24	747	8	10	160
29	85%		Closed	Closed	563.0	659.0	744	56	34	749	31.1	30	41	40	25	749	7	10	80

Table 6 continued: 2005 Main Generator 6

Measured Values																			
Run #	Gate Setting (%)	Unit Load (MW)	Draft Tube Vents	New Main Vents	Tailrace Elev. (feet)	Lake Elevation (feet)	Discharge (cfs)	Tailrace Water Temp (°C)	Rounded Water Temp (°C)	Tailrace Sp. Cond. (uS/cm)	TDG (mmHg)	Measured TDG (% Sat)	Calculated TDG (% Sat)	Calculated P _r -pO ₂ (mmHg)	Nitrogen + Argon (% Sat)	Tailrace DO (mg/L)	Calculated Tailrace DO (% Sat)	Intake DO (mg/L)	Intake Temp (°C)
1	10%	1	Open	Closed	552.5	659.1	409	24.7	24.7	264	876	116	117	749	130	6.80	83.0	0.03	24.5
2	10%	1	Open	Open	552.5	659.1	409	24.6	24.6	265	887	118	118	756	132	7.07	86.3	0.03	24.5
3	10%	1	Closed	Open	552.4	659.2	409	24.5	24.5	265	896	119	119	761	132	7.29	88.7	0.03	24.5
4	20%	3	Closed	Open	552.4	659.2	818	24.6	24.6	265	906	120	121	768	134	7.41	90.4	0.03	24.6
5	20%	3	Open	Closed	552.4	659.2	818	24.5	24.5	265	902	120	120	763	133	7.52	91.6	0.04	24.6
6	30%	7	Open	Closed	552.4	659.2	1,260	24.7	24.7	264	872	116	116	743	129	6.94	84.9	0.12	24.6
7	30%	7	Closed	Open	552.4	659.2	1,260	24.6	24.6	265	872	116	116	750	131	6.59	80.4	0.12	24.7
8	40%	11	Closed	Open	552.4	659.2	1,758	24.7	24.7	264	875	116	117	758	132	6.29	76.9	0.17	24.5
9	40%	11	Open	Closed	552.4	659.2	1,758	24.7	24.7	264	882	117	118	758	132	6.67	81.6	0.16	24.4
10	50%	15	Open	Closed	552.4	659.2	2,239	24.9	24.9	263	874	116	117	754	131	6.44	79.0	0.19	24.5
11	50%	15	Closed	Open	552.5	659.2	2,239	24.9	24.9	263	835	111	111	735	128	5.33	65.4	0.18	24.5
12	60%	19	Closed	Open	552.6	659.2	2,779	24.9	24.9	262	811	108	108	721	126	4.84	59.4	0.21	24.5
13	60%	19	Open	Closed	552.7	659.2	2,779	25.0	25.0	262	876	116	117	757	132	6.38	78.5	0.20	24.5
14	70%	22	Open	Closed	552.8	659.2	3,350	25.1	25.1	262	863	115	115	748	130	6.15	75.8	0.23	24.5
15	70%	22	Closed	Open	553.0	659.2	3,350	25.1	25.1	262	805	107	107	722	126	4.45	54.8	0.25	24.6
16	80%	25	Closed	Open	553.1	659.2	3,947	25.2	25.2	261	776	103	103	702	122	3.97	49.0	0.28	24.6
17	80%	29	Open	Closed	553.2	659.2	3,947	25.2	25.2	261	827	110	110	726	127	5.40	66.6	0.30	24.6
18	90%	29	Open	Closed	553.3	659.2	4,344	25.3	25.3	260	823	109	110	724	126	5.27	65.2	0.29	24.6
19	90%	29	Closed	Open	553.4	659.2	4,344	25.2	25.2	261	760	101	101	692	121	3.64	44.9	0.28	24.6
20	90%	31	Closed	Closed	553.5	659.2	4,344	25.2	25.2	261	703	93	94	658	115	2.42	29.9	0.28	24.6
21	40%	15	Closed	Closed	553.5	659.2	1,758	24.9	24.9	263	705	94	94	664	116	2.18	26.8	0.09	24.5
1	40%	11	Open	Closed	556.4	659.1	1,800	25.3	25.3	264	842	113	113	738	130	5.54	69.3	0.61	24.7
2	40%	10	Open	Open	556.4	659.1	1,800	25.3	25.3	263	848	114	114	743	131	5.59	69.9	0.67	24.7
3	40%	11	Closed	Open	556.3	659.1	1,800	25.2	25.2	263	842	113	113	742	131	5.35	66.8	0.57	24.7
4	60%	19	Closed	Open	556.2	659.1	2,796	25.2	25.2	263	810	109	109	727	128	4.43	55.3	0.20	24.4
5	60%	18	Open	Open	556.2	659.1	2,796	25.7	25.7	263	857	115	115	749	132	5.73	72.2	0.22	24.5
6	60%	19	Open	Closed	556.2	659.1	2,796	25.2	25.2	263	850	114	115	747	132	5.48	68.4	0.22	24.4
7	85%	29	Open	Closed	556.2	659.1	4,136	25.5	25.5	262	824	111	111	732	129	4.87	61.1	0.33	24.5
8	85%	29	Open	Open	556.3	659.1	4,136	25.5	25.5	261	822	110	111	727	128	5.05	63.4	0.36	24.7
9	85%	30	Closed	Open	556.4	659.1	4,136	25.5	25.5	262	743	100	100	684	121	3.12	39.2	0.34	24.7
10	40%	10	Open	Closed	560.2	659.0	1,792	25.9	25.9	260	754	100	102	697	123	3.03	38.4	0.22	25.1
11	40%	10	Open	Open	560.3	659.1	1,792	25.8	25.8	260	839	113	113	745	132	4.95	62.5	0.15	25.0
12	40%	10	Closed	Open	560.2	659.0	1,792	25.9	25.9	260	825	111	111	736	130	4.7	59.5	0.54	25.0
13	60%	19	Closed	Open	560.2	659.0	2,780	26.0	26.0	259	784	105	106	707	125	4.05	51.4	0.54	25.1
14	60%	18	Open	Open	560.2	659.0	2,780	26.0	26.0	259	832	112	112	734	130	5.17	65.6	0.54	25.0
15	60%	20	Open	Closed	560.3	659.0	2,780	26.1	26.1	259	742	100	100	678	120	3.34	42.4	0.56	25.1
16	85%	28	Open	Closed	560.2	659.0	4,059	26.3	26.3	258	760	102	103	690	122	3.69	47.1	0.51	25.1
17	85%	28	Open	Open	560.0	659.0	4,059	26.3	26.3	258	758	102	102	687	122	3.7	47.2	0.43	25.1
18	85%	29	Closed	Open	560.0	659.0	4,059	26.4	26.4	258	698	94	94	648	115	2.6	33.2	0.43	25.1
19	40%	10	Open	Open	563.0	658.9	1,765	26.6	26.6	257	801	107	108	715	126	4.5	57.6	0.40	25.3
20	40%	10	Open	Closed	564.0	658.9	1,765	26.7	26.7	256	708	95	95	653	115	2.85	36.5	0.45	25.4
21	40%	10	Closed	Open	563.1	658.9	1,765	26.6	26.6	256	787	105	106	705	124	4.29	54.9	0.45	25.5
22	60%	18	Closed	Open	563.1	659.0	2,747	26.9	26.9	255	778	104	105	695	123	4.29	55.2	0.45	25.5
23	60%	18	Open	Open	563.1	659.0	2,747	27.0	27.0	255	797	107	107	704	124	4.84	62.2	0.73	25.7
24	60%	19	Open	Closed	563.1	659.0	2,747	27.0	27.0	255	706	94	95	642	113	3.33	42.8	0.86	25.7
25	85%	27	Open	Closed	563.2	659.0	3,980	27.2	27.2	254	715	96	96	642	113	3.78	48.8	0.98	25.7
26	85%	28	Open	Open	563.1	659.1	3,980	27.1	27.1	254	726	97	98	652	115	3.84	49.5	1.04	25.8
27	85%	28	Closed	Open	563.1	659.0	3,980	27.2	27.2	254	692	93	93	629	111	3.27	42.2	0.93	25.8
28	85%	29	Closed	Closed	563.3	659.0	3,980	27.3	27.3	254	692	93	93	627	111	3.34	43.3	1.14	25.8
29	85%		Closed	Closed	563.0	659.0	3,980	27.1	27.1	254	682	91	92	623	110	3.04	39.2	0.96	25.8

Table 6 continued: 2005 Main Generator 6

Calculated Values														
Run #	Gate Setting (%)	Unit Load (MW)	Draft Tube Vents	New Main Vents	Tailrace Elev. (feet)	Lake Elevation (feet)	Aeration Efficiency	Net DO Transfer (mg/L)	O2 in Water (lb./min)	O2 in Air (lb./min)	Air Flow/ Discharge	Oxygen Transfer Efficiency	Oxygen Transfer Rate (lb/hr)	OTR/ Air Discharge
1	10%	1	Open	Closed	552.5	659.1	0.84	6.77	10.38	108.04	0.283	0.10	620	0.06
2	10%	1	Open	Open	552.5	659.1	0.87	7.04	10.79	116.01	0.305	0.09	650	0.06
3	10%	1	Closed	Open	552.4	659.2	0.90	7.26	11.13	116.04	0.307	0.10	670	0.06
4	20%	3	Closed	Open	552.4	659.2	0.91	7.38	22.62	126.68	0.167	0.18	1,360	0.06
5	20%	3	Open	Closed	552.4	659.2	0.93	7.48	22.93	132.51	0.173	0.17	1,380	0.06
6	30%	7	Open	Closed	552.4	659.2	0.86	6.82	32.18	151.63	0.129	0.21	1,930	0.04
7	30%	7	Closed	Open	552.4	659.2	0.81	6.47	30.53	126.97	0.109	0.24	1,830	0.05
8	40%	11	Closed	Open	552.4	659.2	0.78	6.12	40.30	122.98	0.076	0.33	2,420	0.05
9	40%	11	Open	Closed	552.4	659.2	0.82	6.51	42.87	161.60	0.098	0.27	2,570	0.04
10	50%	15	Open	Closed	552.4	659.2	0.80	6.25	52.42	177.94	0.085	0.29	3,150	0.04
11	50%	15	Closed	Open	552.5	659.2	0.66	5.15	43.20	96.84	0.047	0.45	2,590	0.05
12	60%	19	Closed	Open	552.6	659.2	0.59	4.63	48.19	88.39	0.034	0.55	2,890	0.05
13	60%	19	Open	Closed	552.7	659.2	0.79	6.18	64.33	198.65	0.077	0.32	3,860	0.03
14	70%	22	Open	Closed	552.8	659.2	0.76	5.92	74.27	192.09	0.062	0.39	4,460	0.03
15	70%	22	Closed	Open	553.0	659.2	0.54	4.20	52.69	95.83	0.031	0.55	3,160	0.04
16	80%	25	Closed	Open	553.1	659.2	0.48	3.69	54.56	99.45	0.027	0.55	3,270	0.04
17	80%	29	Open	Closed	553.2	659.2	0.66	5.10	75.40	173.58	0.047	0.43	4,520	0.03
18	90%	29	Open	Closed	553.3	659.2	0.65	4.98	81.03	167.82	0.041	0.48	4,860	0.03
19	90%	29	Closed	Open	553.4	659.2	0.44	3.36	54.67	77.89	0.019	0.70	3,280	0.04
20	90%	31	Closed	Closed	553.5	659.2	0.28	2.14	34.82	1.69	0.000	20.65	2,090	1.27
21	40%	15	Closed	Closed	553.5	659.2	0.26	2.09	13.76	1.72	0.001	8.02	830	1.22
1	40%	11	Open	Closed	556.4	659.1	0.66	4.93	33.24	74.41	0.044	0.45	1,990	0.07
2	40%	10	Open	Open	556.4	659.1	0.67	4.92	33.17	128.48	0.078	0.26	1,990	0.04
3	40%	11	Closed	Open	556.3	659.1	0.64	4.78	32.22	87.71	0.054	0.37	1,930	0.05
4	60%	19	Closed	Open	556.2	659.1	0.54	4.23	44.30	66.84	0.026	0.66	2,660	0.06
5	60%	18	Open	Open	556.2	659.1	0.71	5.51	57.71	160.99	0.063	0.36	3,460	0.03
6	60%	19	Open	Closed	556.2	659.1	0.67	5.26	55.09	146.59	0.056	0.38	3,310	0.04
7	85%	29	Open	Closed	556.2	659.1	0.59	4.54	70.34	118.96	0.031	0.59	4,220	0.04
8	85%	29	Open	Open	556.3	659.1	0.61	4.69	72.66	125.42	0.033	0.58	4,360	0.04
9	85%	30	Closed	Open	556.4	659.1	0.36	2.78	43.07	37.22	0.010	1.16	2,580	0.07
10	40%	10	Open	Closed	560.2	659.0	0.36	2.81	18.86	16.97	0.010	1.11	1,130	0.17
11	40%	10	Open	Open	560.3	659.1	0.61	4.80	32.21	61.33	0.037	0.53	1,930	0.08
12	40%	10	Closed	Open	560.2	659.0	0.56	4.16	27.92	51.09	0.032	0.55	1,680	0.08
13	60%	19	Closed	Open	560.2	659.0	0.48	3.51	36.55	48.37	0.019	0.76	2,190	0.07
14	60%	18	Open	Open	560.2	659.0	0.63	4.63	48.22	96.44	0.038	0.50	2,890	0.05
15	60%	20	Open	Closed	560.3	659.0	0.38	2.78	28.95	49.19	0.019	0.59	1,740	0.06
16	85%	28	Open	Closed	560.2	659.0	0.43	3.18	48.35	50.96	0.014	0.95	2,900	0.06
17	85%	28	Open	Open	560.0	659.0	0.44	3.27	49.72	51.34	0.014	0.97	2,980	0.06
18	85%	29	Closed	Open	560.0	659.0	0.29	2.17	33.00	9.19	0.003	3.59	1,980	0.24
19	40%	10	Open	Open	563.0	658.9	0.55	4.10	27.11	71.60	0.044	0.38	1,630	0.06
20	40%	10	Open	Closed	564.0	658.9	0.33	2.40	15.87	1.40	0.001	11.35	950	1.72
21	40%	10	Closed	Open	563.1	658.9	0.52	3.84	25.39	33.72	0.021	0.75	1,520	0.11
22	60%	18	Closed	Open	563.1	659.0	0.53	3.84	39.50	39.02	0.016	1.01	2,370	0.10
23	60%	18	Open	Open	563.1	659.0	0.59	4.11	42.28	61.33	0.024	0.69	2,540	0.07
24	60%	19	Open	Closed	563.1	659.0	0.36	2.47	25.41	1.55	0.001	16.36	1,520	1.59
25	85%	27	Open	Closed	563.2	659.0	0.42	2.80	41.74	19.41	0.005	2.15	2,500	0.14
26	85%	28	Open	Open	563.1	659.1	0.42	2.80	41.74	23.46	0.006	1.78	2,500	0.12
27	85%	28	Closed	Open	563.1	659.0	0.35	2.34	34.88	2.57	0.001	13.57	2,090	0.91
28	85%	29	Closed	Closed	563.3	659.0	0.34	2.20	32.79	2.50	0.001	13.13	1,970	0.88
29	85%		Closed	Closed	563.0	659.0	0.31	2.08	31.00	1.25	0.000	24.89	1,860	1.67

Table 7: 2005 Main Generator 3 Data

Measured Values															
Run #	Gate Setting (%)	Unit Load (MW)	Number of Main Vents Open	Tailrace Elev. (feet)	Lake Elevation (feet)	Tailrace Baro Press. (mmHg)	Relative Humidity (%)	Turbine Barrel Air Temp (°C)	Turbine Barrel Baro Pressure (mmHg)	Main Vent Air Flows (cfm)	Main Vent Standard Air Flows (scfm)	Discharge (cfs)	Tailrace Water Temp (°C)	Rounded Water Temp (°C)	Tailrace Sp. Cond. (uS/cm)
1	40%	9	4	556.4	659.1	742	48	36	748	7,422	6,820	1,784	25.1	25.1	293
2	40%	9	2	556.4	659.1	742	46	36	748	6,677	6,140	1,784	25.0	25.0	294
3	40%	9	1	556.3	659.1	742	46	36	747	4,801	4,410	1,784	25.0	25.0	293
4	60%	16	1	556.2	659.1	742	46	36	747	5,143	4,720	2,760	25.1	25.1	293
5	60%	15	2	556.2	659.1	742	44	36	747	7,504	6,880	2,760	25.1	25.1	293
6	60%	15	4	556.2	659.1	742	44	36	747	8,320	7,630	2,760	25.1	25.1	293
7	85%	25	3	556.2	659.1	742	44	36	747	7,120	6,530	4,185	25.4	25.4	292
8	85%	26	2	556.3	659.1	742	45	36	747	6,870	6,300	4,185	25.4	25.4	292
9	85%	27	1	556.4	659.1	741	44	36	747	5,070	4,640	4,185	25.4	25.4	292
10	40%	8	4	560.2	659.0	741	42	37	747	4,413	4,040	1,767	25.3	25.3	292
11	40%	8	2	560.3	659.1	741	45	36	746	4,364	3,990	1,767	25.4	25.4	292
12	40%	8	1	560.2	659.0	741	45	36	746	3,765	3,450	1,767	25.3	25.3	292
13	60%	15	1	560.2	659.0	741	45	36	746	4,190	3,840	2,745	25.5	25.5	291
14	60%	15	2	560.2	659.0	741	45	36	746	4,957	4,540	2,745	25.6	25.6	291
15	60%	15	4	560.3	659.0	741	44	37	746	5,654	5,170	2,745	25.5	25.5	291
16	85%	25	4	560.2	659.0	741	46	37	746	5,523	5,050	4,184	25.8	25.8	291
17	85%	26	2	560.0	659.0	741	47	36	746	5,645	5,170	4,184	25.8	25.8	291
18	85%	27	1	560.0	659.0	741	49	36	746	4,546	4,160	4,184	25.8	25.8	291
19	40%	6	4	563.0	658.9	742	50	36	747	2,684	2,470	1,755	26.5	26.5	287
20	40%	6	2	564.0	658.9	743	51	36	747	2,694	2,480	1,755	26.0	26.0	290
21	40%	6	1	563.1	659.0	743		35	747	2,272	2,090	1,755	26.0	26.0	289
22	60%	15	1	563.1	659.0	743	55	35	748	4,232	3,910	2,745	26.4	26.4	289
23	60%	14	2	563.0	659.0	744	54	35	749	3,981	3,670	2,745	26.3	26.3	288
24	60%	14	4	563.1	659.0	744	55	35	749	4,084	3,770	2,745	26.4	26.4	287
25	85%	25	4	563.2	659.0	744	54	35	749	4,634	4,280	4,179	26.4	26.4	288
26	85%	25	2	563.1	659.1	744	56	35	749	4,709	4,350	4,179	26.6	26.6	286
27	85%	26	1	563.0	659.0	744	56	34	749	4,110	3,800	4,179	26.5	26.5	287
28	85%	29	None	563.3	659.0	742	49	36	747	95	90	4,179	26.4	26.4	291
29	85%		None	563.0	659.0	744	56	34	749	776	720	4,179	26.3	26.3	288

Table 7 continued: 2005 Main Generator 3 Data

Measured Values														
Run #	Gate Setting (%)	Unit Load (MW)	Number of Main Vents Open	Tailrace Elev. (feet)	Lake Elevation (feet)	TDG (mmHg)	Measured TDG (% Sat)	Calculated TDG (% Sat)	Calculated PT-pO2 (mmHg)	Nitrogen + Argon (% Sat)	Tailrace DO (mg/L)	Calculated Tailrace DO (% Sat)	Intake DO (mg/L)	Intake Temp (°C)
1	40%	9	4	556.4	659.1	803	107	108	692	122	5.95	74.1	0.15	25.5
2	40%	9	2	556.4	659.1	856	115	115	744	131	5.98	74.4	0.20	25.5
3	40%	9	1	556.3	659.1	842	113	113	739	130	5.53	68.8	0.24	25.5
4	60%	16	1	556.2	659.1	819	110	110	731	129	4.72	58.8	0.23	25.6
5	60%	15	2	556.2	659.1	845	113	114	748	132	5.20	64.8	0.32	25.6
6	60%	15	4	556.2	659.1	854	114	115	751	132	5.50	68.5	0.32	25.6
7	85%	25	3	556.2	659.1	820	110	111	732	129	4.69	58.7	0.46	25.8
8	85%	26	2	556.3	659.1	812	109	109	722	127	4.80	60.1	0.52	25.9
9	85%	27	1	556.4	659.1	796	107	107	718	127	4.15	52.1	0.48	25.8
10	40%	8	4	560.2	659.0	829	111	112	741	131	4.66	58.3	0.22	25.8
11	40%	8	2	560.3	659.1	851	114	115	760	134	4.86	61.0	0.21	25.8
12	40%	8	1	560.2	659.0	811	109	109	730	129	4.29	53.7	0.18	25.8
13	60%	15	1	560.2	659.0	796	107	107	720	127	4.01	50.4	0.43	26.0
14	60%	15	2	560.2	659.0	820	110	111	736	130	4.44	55.9	0.43	26.0
15	60%	15	4	560.3	659.0	830	111	112	739	131	4.82	60.6	0.50	26.0
16	85%	25	4	560.2	659.0	813	109	110	722	128	4.82	60.9	0.55	26.1
17	85%	26	2	560.0	659.0	816	109	110	729	129	4.61	58.3	0.58	26.0
18	85%	27	1	560.0	659.0	792	106	107	716	126	4.02	50.8	0.59	26.1
19	40%	6	4	563.0	658.9	811	109	109	731	129	4.20	53.7	0.58	26.3
20	40%	6	2	564.0	658.9	808	108	109	731	129	4.04	51.1	0.46	26.2
21	40%	6	1	563.1	659.0	807	108	109	730	129	4.06	51.3	0.47	26.2
22	60%	15	1	563.1	659.0	778	104	105	702	124	3.95	50.3	0.98	26.4
23	60%	14	2	563.0	659.0	818	110	110	725	128	4.86	61.7	1.03	26.6
24	60%	14	4	563.1	659.0	808	108	109	721	127	4.57	58.1	1.12	26.6
25	85%	25	4	563.2	659.0	779	104	105	693	122	4.47	56.9	1.67	27.0
26	85%	25	2	563.1	659.1	776	104	104	695	122	4.24	54.1	1.51	27.0
27	85%	26	1	563.0	659.0	759	102	102	685	121	3.86	49.2	1.54	26.9
28	85%	29	None	563.3	659.0	688	92	93	624	110	3.36	42.9	1.94	27.2
29	85%		None	563.0	659.0	683	91	92	635	112	2.52	32.0	1.82	26.7

Table 7 continued: 2005 Main Generator 3 Data

Calculated Values													
Run #	Gate Setting (%)	Unit Load (MW)	Number of Main Vents Open	Tailrace Elev. (feet)	Lake Elevation (feet)	Aeration Efficiency	Net DO Transfer (mg/L)	O2 in Water (lb./min)	O2 in Air (lb./min)	Air Flow/ Discharge	Oxygen Transfer Efficiency	Oxygen Transfer Rate (lb/hr)	OTR/ Air Discharge
1	40%	9	4	556.4	659.1	0.73	5.80	38.75	102.78	0.064	0.38	2,320	0.06
2	40%	9	2	556.4	659.1	0.73	5.78	38.61	92.53	0.057	0.42	2,320	0.06
3	40%	9	1	556.3	659.1	0.67	5.29	35.34	66.46	0.041	0.53	2,120	0.08
4	60%	16	1	556.2	659.1	0.57	4.49	46.41	70.88	0.029	0.65	2,780	0.06
5	60%	15	2	556.2	659.1	0.63	4.88	50.44	103.32	0.042	0.49	3,030	0.05
6	60%	15	4	556.2	659.1	0.67	5.18	53.55	114.58	0.046	0.47	3,210	0.05
7	85%	25	3	556.2	659.1	0.56	4.23	66.31	98.06	0.026	0.68	3,980	0.04
8	85%	26	2	556.3	659.1	0.57	4.28	67.10	94.61	0.025	0.71	4,030	0.05
9	85%	27	1	556.4	659.1	0.49	3.67	57.53	69.68	0.018	0.83	3,450	0.05
10	40%	8	4	560.2	659.0	0.57	4.44	29.38	60.67	0.038	0.48	1,760	0.07
11	40%	8	2	560.3	659.1	0.59	4.65	30.77	59.92	0.038	0.51	1,850	0.08
12	40%	8	1	560.2	659.0	0.52	4.11	27.20	51.81	0.033	0.52	1,630	0.08
13	60%	15	1	560.2	659.0	0.47	3.58	36.81	57.67	0.023	0.64	2,210	0.06
14	60%	15	2	560.2	659.0	0.53	4.01	41.23	68.18	0.028	0.60	2,470	0.06
15	60%	15	4	560.3	659.0	0.57	4.32	44.42	77.64	0.031	0.57	2,670	0.06
16	85%	25	4	560.2	659.0	0.58	4.27	66.92	75.84	0.020	0.88	4,020	0.06
17	85%	26	2	560.0	659.0	0.55	4.03	63.16	77.64	0.021	0.81	3,790	0.05
18	85%	27	1	560.0	659.0	0.46	3.43	53.75	62.47	0.017	0.86	3,230	0.05
19	40%	6	4	563.0	658.9	0.50	3.62	23.79	37.22	0.023	0.64	1,430	0.10
20	40%	6	2	564.0	658.9	0.48	3.58	23.53	37.37	0.024	0.63	1,410	0.10
21	40%	6	1	563.1	659.0	0.48	3.59	23.59	31.50	0.020	0.75	1,420	0.11
22	60%	15	1	563.1	659.0	0.43	2.97	30.54	59.13	0.024	0.52	1,830	0.05
23	60%	14	2	563.0	659.0	0.56	3.83	39.38	55.50	0.022	0.71	2,360	0.07
24	60%	14	4	563.1	659.0	0.51	3.45	35.47	57.01	0.023	0.62	2,130	0.06
25	85%	25	4	563.2	659.0	0.45	2.80	43.83	64.72	0.017	0.68	2,630	0.04
26	85%	25	2	563.1	659.1	0.43	2.73	42.74	65.78	0.017	0.65	2,560	0.04
27	85%	26	1	563.0	659.0	0.37	2.32	36.32	57.47	0.015	0.63	2,180	0.04
28	85%	29	None	563.3	659.0	0.24	1.42	22.23	1.36	0.000	16.39	1,330	1.05
29	85%		None	563.0	659.0	0.12	0.70	10.96	10.89	0.003	1.01	660	0.06