# FLOW RATING ANALYSIS FOR PUMP STATION S200


**By**
**Sheng Yue & Emile Damisse**

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**Hydro Data Management Section**
**Operation & Infrastructure Bureau**
**South Florida Water Management District**

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# ACKNOWLEDGEMENT

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# DEFINITIONS

## Acronyms

| | |
|---|---|
| AARE | Average absolute relative error |
| ARE | Absolute relative error |
| HW | Head water |
| TW | Tail water |
| SFWMD | South Florida Water Management District |
| TDH | Total dynamic head |
| TSH | Total static head |

# EXECUTIVE SUMMARY

Pump Station S200 consists of three identical electric pumps each with capacity of 75 cfs. This report summarizes a flow rating analysis for the pumps at Pump Station S200 based on the TSH vs. discharge relationship obtained from the pump performance tests with the calibration using the two flow measurements. The developed rating equation will be used to compute flow through the pump station.

# 1.0 INTRODUCTION

## 1.1 Background

Pump Station S200 is one of key components of the northern section of the C-111 Spreader Canal Phase 1 Project, which is located in southern Miami-Dade County in an area bounded by Everglades National Park, the Florida City-Homestead area, and Manatee. The main north portion of the project includes the Frog Pond Detention Area (FPDA), the Frog Pond Header Distribution Channel, and Pump Station S200.

The primary purpose of Pump Station S200 is to re-direct to the west up to 225 cfs of excess water from C111 Canal into FPDA. Pump Station S200 with design capacity of 225 cfs is located downstream of the existing S-176 structure, north of Ingraham Highway and west of the C-111 Canal along the northern boundary of the FPDA. **Figure 1** shows the location of the pump station.

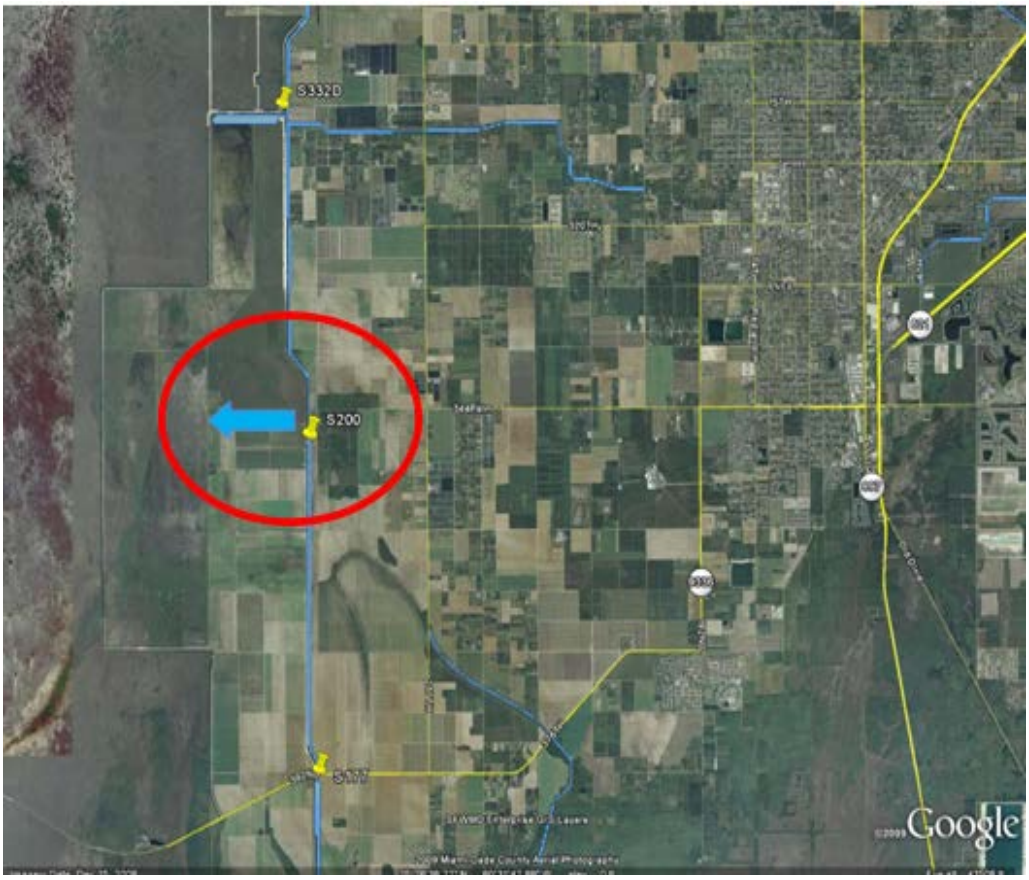


**Fig 1.** Location of Pump Station S200

## 1.2 Objectives and Scope

We will conduct a rating analysis to develop a flow rating equation for Pump Station S200 to compute flow through the pump station.

# 2.0 STATION DESIGN

Pump Station S200 houses three identical electric pumps with pump serial number SN10021, SN10022, and SN10023, each with capacity of 75 cfs. **Figure 2** illustrates the plan view of the pump station, and **Figure 3** the profile view of the pump station. **Table 1** provides description of the pump station.

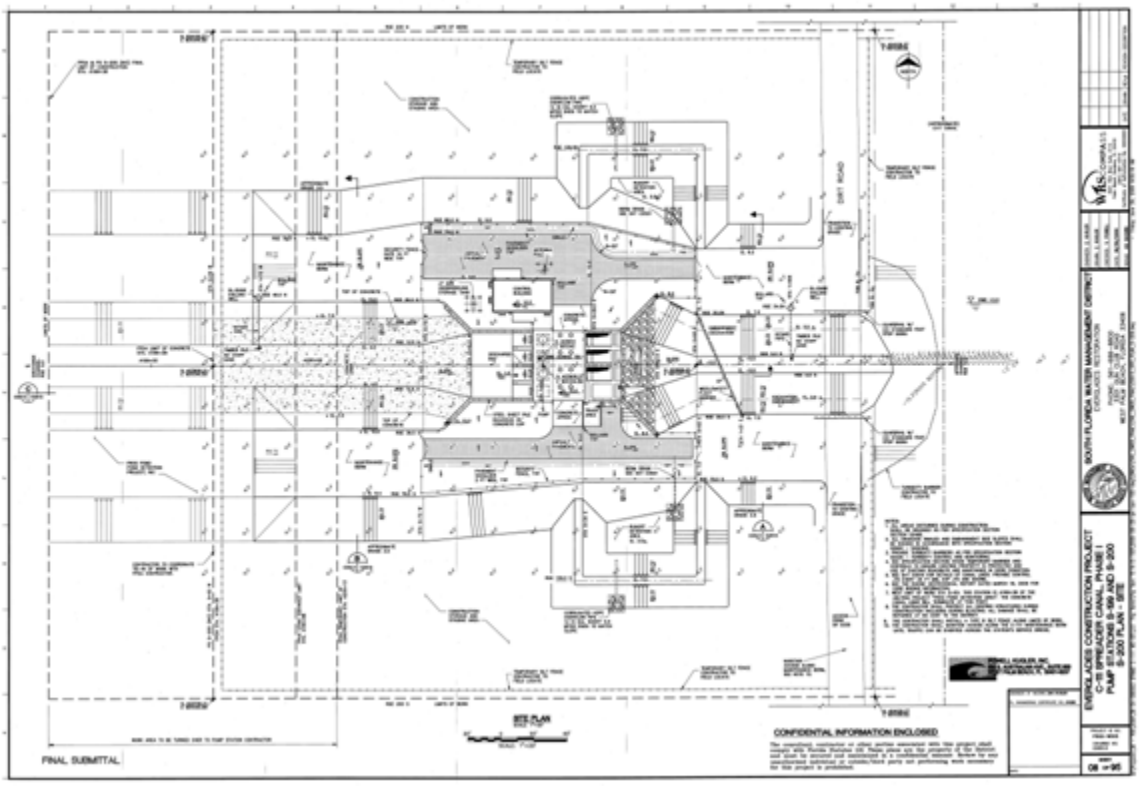


**Figure 2**. Plan view of Pump Station S200

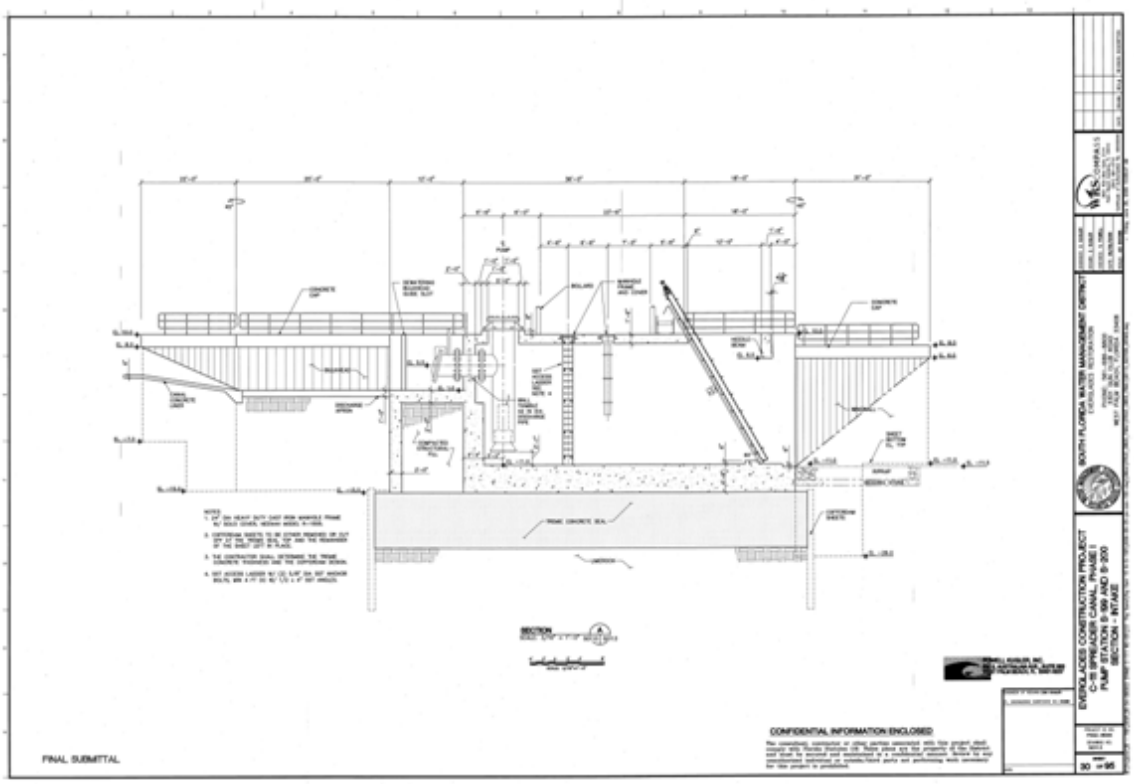


**Figure 3**. Profile view of Pump Station S200

**Table 1. Description for Pump Station S200**

| ITEM | Description |
|---|---|
| Number of pumps | 3 |
| Design pump capacity | 75 cfs |
| Engine motor horsepower | 200 Hp |
| Design engine speed | 588 rpm |
| Pump impeller speed | 588 rpm |
| Propeller Diameter | 30 in |
| Discharge pipe diameter | 42 in |

## 2.1. Pump Performance Test

The manufacturer conducted pump performance tests on these three pumps. The total dynamic head (TDH) computations of these pumps are given in Appendix A through C (MWI Corporation, 2011). **Table 2** below presents the total static head (TSH) versus discharge values which were extracted from Appendix A through C.

**Table 2. Initial TSH and Discharge Relationship**

| Pump Serial No | Test Point | Pressure gauge height (in) | Static pressure (psi) | TSH (ft) | Flow (gpm) | Flow (cfs) |
|---|---|---|---|---|---|---|
| **SN 10021** | 1 | 26 | 6.35 | 16.82 | 32465 | 72.33 |
| | 2 | 26 | 5.00 | 13.70 | 34194 | 76.19 |
| | 3 | 26 | 4.10 | 11.63 | 35378 | 78.82 |
| | 4 | 26 | 3.00 | 9.09 | 36297 | 80.87 |
| | 5 | 26 | 2.00 | 6.78 | 37193 | 82.87 |
| | 6 | 26 | 1.15 | 4.82 | 38068 | 84.82 |
| | 7 | 26 | 0.00 | 2.17 | 39345 | 87.66 |
| **SN10022** | 1 | 27 | 5.80 | 15.63 | 32465 | 72.33 |
| | 2 | 27 | 4.90 | 13.55 | 34194 | 76.19 |
| | 3 | 27 | 3.90 | 11.25 | 35378 | 78.82 |
| | 4 | 27 | 3.00 | 9.17 | 36297 | 80.87 |
| | 5 | 27 | 2.00 | 6.86 | 37193 | 82.87 |
| | 6 | 27 | 1.00 | 4.56 | 38068 | 84.82 |
| | 7 | 27 | 0.00 | 2.25 | 39345 | 87.66 |
| **SN10023** | 1 | 27 | 6.00 | 16.09 | 32210 | 71.77 |
| | 2 | 27 | 5.00 | 13.79 | 33952 | 75.65 |
| | 3 | 27 | 4.00 | 11.48 | 34909 | 77.78 |
| | 4 | 27 | 3.10 | 9.40 | 36069 | 80.36 |
| | 5 | 27 | 2.00 | 6.86 | 37414 | 83.36 |
| | 6 | 27 | 1.10 | 4.79 | 38284 | 85.30 |
| | 7 | 27 | 0.00 | 2.25 | 38924 | 86.73 |

# 3.0 STREAM FLOW DATA

We conducted streamgauging at Pump Station S200 using Acoustic Doppler Current Profiler (ADCP) on February 23, 2012, and at Pump Station S199 on March 7, 2012. We can borrow the measured flow at S199 to calibrate the flow rating for S200 since the two stations have identical pump station design and identical pumps. **Table 3** summarizes the flow measurement, including the HW and TW stage, number of pumps in operation, engine speed, average discharge, and measurement quality tag. The quality of each flow measurement has been evaluated and assigned quality tag or qualitative accuracy qualifier by our stream gauging staff. There are six categories of qualifiers are used: “excellent (E)”, “good (G)”, “fair (F)”, “poor (P)”, “bad (B)”, and “Not processed (N).

**Table 3. Summary of Flow Measurements**

| Date | HW Stage (ft, NGVD) | TW Stage (ft, NGVD) | # of Units | Avg Engine Speed (rpm) | Avg Discharge (cfs) | Device | Quality Tag |
|---|---|---|---|---|---|---|---|
| 2/23/2012 | 3.01 | 8.70 | 3 | 588 | 225.56 | ADCP | G |
| 3/7/2012 | 2.26 | 7.80 | 2 | 588 | 224.48 | ADCP | G |

# 4.0 RATING ANALYSIS

We will develop a Case 8 flow rating equation for Pump Station S200 based on the TSH vs. discharge relationship obtained from the pump performance tests. Case 8 rating equation is developed by dimensional analysis and the pump affinity laws. Case 8 rating is the conventional rating equation representing all the possible cases, as documented in Damisse (2001) and Imru and Wang (2003). Equation below shows the Case 8 flow rating equation.

$$Q = A\left(\frac{N}{No}\right) + BH^{C}\left(\frac{No}{N}\right)^{2C-1} \quad (1)$$

$$H = \max\{CL, TW\} - HW \quad (2)$$

Where

| | |
|---|---|
| *Q*: | Discharge in cfs; |
| *H*: | Total static head (TSH); |
| *N*: | Pump engine speed in rpm; |
| *No*: | Design pump engine speed in rpm (= 588 rpm); |
| *A*, *B* and *C*: | Regression coefficients determined through regression analysis (A > 0, B < 0, and C > 1.0). |
| *CL*: | Discharge pipe outlet centerline elevation; |
| *TW*: | Tailwater elevation; |
| *HW*: | Headwater elevation. |

For an electric pump with constant speed, $N = N_o$, and Equation (1) becomes

$$Q = A + BH^{C} \quad (3)$$

We conducted rating analysis by nonlinear regression analysis based on TSH vs. discharge values in **Table 2**. **Figure 4** shows comparison of computed flows against tested data and measured flows. It

illustrates that the developed rating curve fits the tested data well, but is far away from the measured flows. **Table 4** lists the AARE between measured and computed flows and AARE is 12.5%. This indicates that given a TSH, the rating might overestimate flow through the pump station by 12.5%. Hence, the developed rating based on the tested data cannot represent real flow capacity of the pumps.

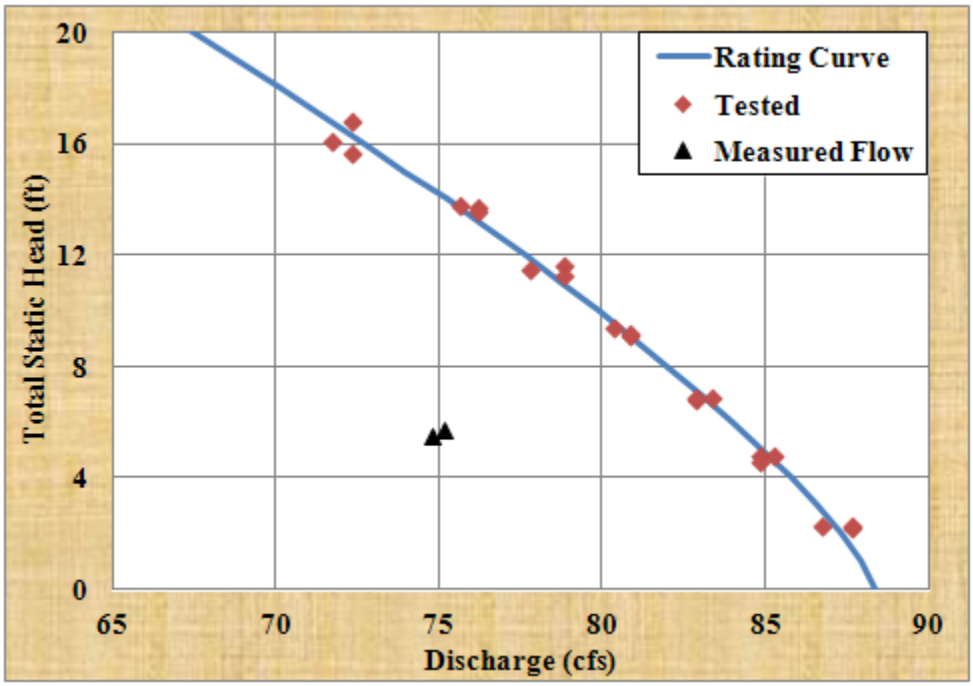


**Figure 4**. Comparison between measured flows and developed rating

**Table 4. Initial Comparison between Measured and Computed Flows**

| Date | HW Stage (ft, NGVD) | TW Stage (ft, NGVD) | Avg Discharge (cfs) | Computed Flow (cfs) | ARE (%) |
|---|---|---|---|---|---|
| 2/23/2012 | 3.01 | 8.70 | 75.2 | 84.3 | 12.1 |
| 3/7/2012 | 2.26 | 7.80 | 74.8 | 84.4 | 12.8 |
| **AARE (%)** | | | | | **12.5** |

Each of the three pumps at Pump Station S200 has design capacity of 75 cfs. Our measured flow rates were close to the design capacity of the pump when all three pumps were running. Quality of the flow measurements are good and reliable based on our engineering judgment. The developed rating curve needs to be shifted near the measured flows. We shifted the developed rating curve using Eq. (1) by giving lower engine speed, i.e., $N$ = 530 rpm and got the shifted curve which is in parallel with the original one. **Table 5 presents** TSH vs. discharge values from the shifted rating. We then conducted non-

linear regression analysis on the shifted TSH vs. discharge values in **Table 5** to estimate rating coefficients in Equation (3). **Table 6** provides the flow rating equation coefficients of Eq. (3).

**Table 5. TSH and Discharge from Shifted Rating Curve**

| Total Static Head (ft) | Discharge (cfs) |
|---|---|
| 0.0 | 79.660 |
| 0.5 | 79.456 |
| 1.0 | 79.157 |
| 1.5 | 78.808 |
| 2.0 | 78.422 |
| 3.0 | 77.563 |
| 4.0 | 76.613 |
| 5.0 | 75.588 |
| 6.0 | 74.500 |
| 7.0 | 73.356 |
| 8.0 | 72.161 |
| 9.0 | 70.922 |
| 10.0 | 69.640 |
| 11.0 | 68.319 |
| 12.0 | 66.962 |
| 13.0 | 65.571 |

**Table 6. Flow Rating Coefficients for the Pumps at S200**

| Rating Coefficient | Estimate | Approximate Lower 95% Confidence Limit | Approximate Upper 95% Confidence Limit |
|---|---|---|---|
| A | 79.661 | 79.6601 | 79.661 |
| B | -0.503 | -0.5035 | -0.5032 |
| C | 1.299 | 1.2989 | 1.2991 |

**Figure 5** illustrates the developed rating curve for the pumps at Pump Station S200. The diagram indicates that the rating curve from the developed rating equation well fits both the shifted data and measured flows. **Table 7** presents the relative errors between tested and calculated flows, and the AARE between tested and calculated flows is 0.4%. These results demonstrate that the developed rating can represent the relationship between total static head and discharge of the pump station.

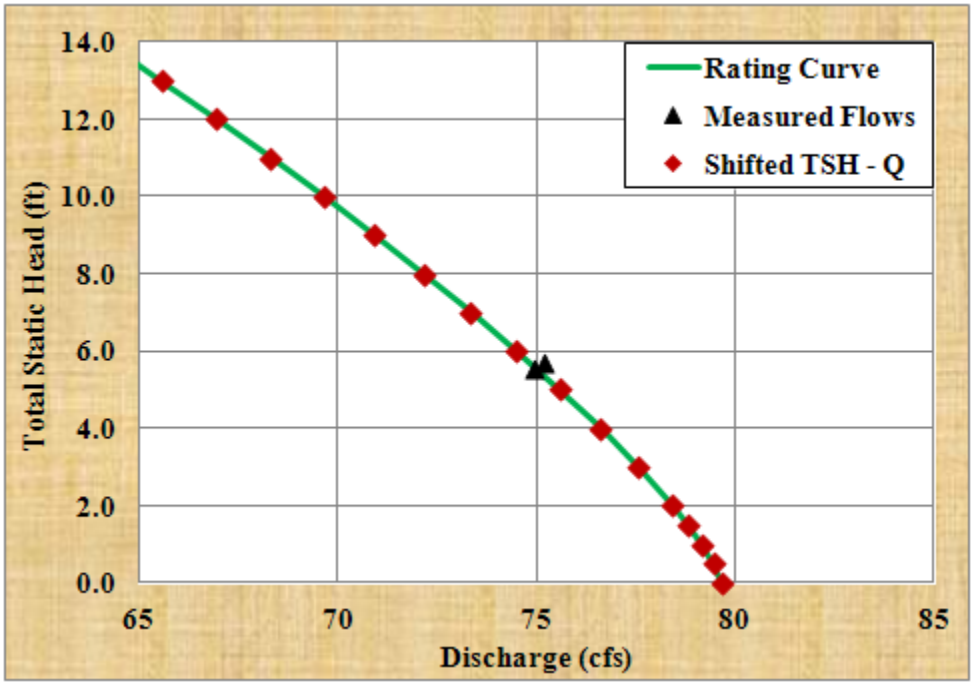


**Figure 5**. Rating Curve for Pump Station S200

**Table 7. Comparison between Measured and Computed Flows**

| Date | HW Stage (ft, NGVD) | TW Stage (ft, NGVD) | Avg Discharge (cfs) | Computed Flow (cfs) | ARE (%) |
|---|---|---|---|---|---|
| 2/23/2012 | 3.10 | 8.70 | 75.2 | 74.8 | 0.5 |
| 3/7/2012 | 2.26 | 7.80 | 74.8 | 75.0 | 0.2 |
| **AARE (%)** | | | | | **0.4** |

## 5.0 CONCLUDING REMARKS

We conducted rating analysis for Pump Station S200 based on the TSH vs. discharge relationship obtained from the pump performance tests. We then adjusted the rating based on the measured flows. **Table 6** presents the coefficients of the rating equation for Pump Station S200. The rating can be used to compute flow through Pump Station S200 for now. However, it needs to be further calibrated, and to be potentially improved based on more flow measurements in the future.

# REFERENCES

Damisse, E. 2001. Flow rating development for G335 Pump Station in STA-2. Hydrologic Data Management Division, South Florida Water Management District, West Palm Beach, Florida.

Imru, M. and Y. Wang. 2003. Flow Rating Analysis Procedures for Pumps. Technical Publication EMA # 413, South Florida Water Management District, West Palm Beach, Florida.

MWI Corporation, 2011. South Florida Water Management District S-199 & S-200 Pump Stations: Full Size Pump Performance Test, MWI JOB # 10021, Deerfield Beach, Florida.

## Appendix A. SN 10021 TDH calculation

| | | | | | |
|---|---|---|---|---|---|
| Test date | 21-Jan-11 | | pressure gauge height | 26 |
| Pump Model Description | SEA330 | | motor full load current (FLA) | 328 |
| Pump Serial No | 10021 | | friction k value (pipe) | 0.05 |
| Water pump speed | 588 | rpm | friction k value (for motor region) | 4.49 |
| Test pipe ID | 41.5 | inches | friction k value (for discharge elbow) | 0.78 |

| Test Point | pump speed (rpm) | Static Pressure (psi) | Venturi reading ("$H_20$) | electric power into motor (amps) | (kWs) |
|---|---|---|---|---|---|
| 1 | | 6.35 | 32.0 | 338 | 177 |
| 2 | | 5.0 | 35.5 | 326 | 169 |
| 3 | | 4.1 | 38.0 | 315 | 163 |
| 4 | | 3.0 | 40.0 | 305 | 155 |
| 5 | | 2.0 | 42.0 | 295 | 146 |
| 6 | | 1.15 | 44.0 | 287 | 141 |
| 7 | | 0.0 | 47.0 | 271 | 128 |

| Vel (ft/sec) | Hv (ft) | pipe pipe friction Hf (ft) | motor region friction Hf (ft) | disch elbow friction Hf (ft) | **Flow (gpm)** | **TDH (ft)** | WHP |
|---|---|---|---|---|---|---|---|
| 7.70 | 0.92 | 0.05 | 4.13 | 0.72 | **32465** | **22.6** | 185.6 |
| 8.11 | 1.02 | 0.05 | 4.59 | 0.80 | **34194** | **20.2** | 174.0 |
| 8.39 | 1.09 | 0.05 | 4.91 | 0.85 | **35378** | **18.5** | 165.6 |
| 8.61 | 1.15 | 0.06 | 5.17 | 0.90 | **36297** | **16.4** | 150.0 |
| 8.82 | 1.21 | 0.06 | 5.43 | 0.94 | **37193** | **14.4** | 135.4 |
| 9.03 | 1.27 | 0.06 | 5.68 | 0.99 | **38068** | **12.8** | 123.2 |
| 9.33 | 1.35 | 0.07 | 6.07 | 1.05 | **39345** | **10.7** | 106.4 |

## Appendix B. SN 10022 TDH calculation

| | | | | | |
|---|---|---|---|---|---|
| Test date | 25-Jan-11 | | pressure gauge height | 27 |
| Pump Model Description | SEA330 | | motor full load current (FLA) | 328 |
| Pump Serial No | 10022 | | friction k value (pipe) | 0.05 |
| Water pump speed | 588 | rpm | friction k value (for motor region) | 4.49 |
| Test pipe ID | 41.5 | inches | friction k value (for discharge elbow) | 0.78 |

| Test Point | pump speed (rpm) | Static Pressure (psi) | Venturi reading ("$H_20$) | electric power into motor (amps) | (kWs) |
|---|---|---|---|---|---|
| 1 | | 5.8 | 34.0 | 348 | 179 |
| 2 | | 4.9 | 36.5 | 335 | 170 |
| 3 | | 3.9 | 38.5 | 323 | 163 |
| 4 | | 3.0 | 41.0 | 313 | 156 |
| 5 | | 2.0 | 42.5 | 301 | 147 |
| 6 | | 1.0 | 45.0 | 290 | 140 |
| 7 | | 0.0 | 46.5 | 278 | 130 |

| Vel (ft/sec) | Hv (ft) | pipe pipe friction Hf (ft) | motor region friction Hf (ft) | disch elbow friction Hf (ft) | **Flow (gpm)** | **TDH (ft)** | WHP |
|---|---|---|---|---|---|---|---|
| 7.94 | 0.98 | 0.05 | 4.39 | 0.76 | **33464** | **21.8** | 184.3 |
| 8.22 | 1.05 | 0.05 | 4.72 | 0.82 | **34672** | **20.2** | 176.8 |
| 8.45 | 1.11 | 0.06 | 4.97 | 0.86 | **35610** | **18.2** | 164.1 |
| 8.72 | 1.18 | 0.06 | 5.30 | 0.92 | **36748** | **16.6** | 154.3 |
| 8.87 | 1.22 | 0.06 | 5.49 | 0.95 | **37414** | **14.6** | 137.9 |
| 9.13 | 1.29 | 0.06 | 5.81 | 1.01 | **38498** | **12.7** | 123.9 |
| 9.28 | 1.34 | 0.07 | 6.01 | 1.04 | **39135** | **10.7** | 105.8 |

## Appendix C. SN 10023 TDH calculation

| | | | | | |
|---|---|---|---|---|---|
| Test date | 24-Mar-11 | | pressure gauge height | 27 |
| Pump Model Description | SEA330 | | motor full load current (FLA) | 328 |
| Pump Serial No | 10023 | | friction k value (pipe) | 0.05 |
| Water pump speed | 588 | rpm | friction k value (for motor region) | 4.49 |
| Test pipe ID | 41.5 | inches | friction k value (for discharge elbow) | 0.78 |

| Test Point | pump speed (rpm) | Static Pressure (psi) | Venturi reading ("$H_20$) | electric power into motor (amps) | (kWs) |
|---|---|---|---|---|---|
| 1 | | 6.0 | 31.5 | 330 | 174 |
| 2 | | 5.0 | 35.0 | 321 | 168 |
| 3 | | 4.0 | 37.0 | 316 | 162 |
| 4 | | 3.1 | 39.5 | 306 | 156 |
| 5 | | 2.0 | 42.5 | 279 | 133 |
| 6 | | 1.1 | 44.5 | 269 | 125 |
| 7 | | 0.0 | 46.0 | 267 | 122 |

| Vel (ft/sec) | Hv (ft) | pipe pipe friction Hf (ft) | motor region friction Hf (ft) | disch elbow friction Hf (ft) | **Flow (gpm)** | **TDH (ft)** | WHP |
|---|---|---|---|---|---|---|---|
| 7.64 | 0.91 | 0.05 | 4.07 | 0.71 | **32210** | **21.8** | 177.5 |
| 8.05 | 1.01 | 0.05 | 4.52 | 0.79 | **33952** | **20.1** | 172.8 |
| 8.28 | 1.06 | 0.05 | 4.78 | 0.83 | **34909** | **18.2** | 160.5 |
| 8.56 | 1.14 | 0.06 | 5.10 | 0.89 | **36069** | **16.6** | 151.1 |
| 8.87 | 1.22 | 0.06 | 5.49 | 0.95 | **37414** | **14.6** | 137.9 |
| 9.08 | 1.28 | 0.06 | 5.75 | 1.00 | **38284** | **12.9** | 124.5 |
| 9.23 | 1.32 | 0.07 | 5.94 | 1.03 | **38924** | **10.6** | 104.3 |