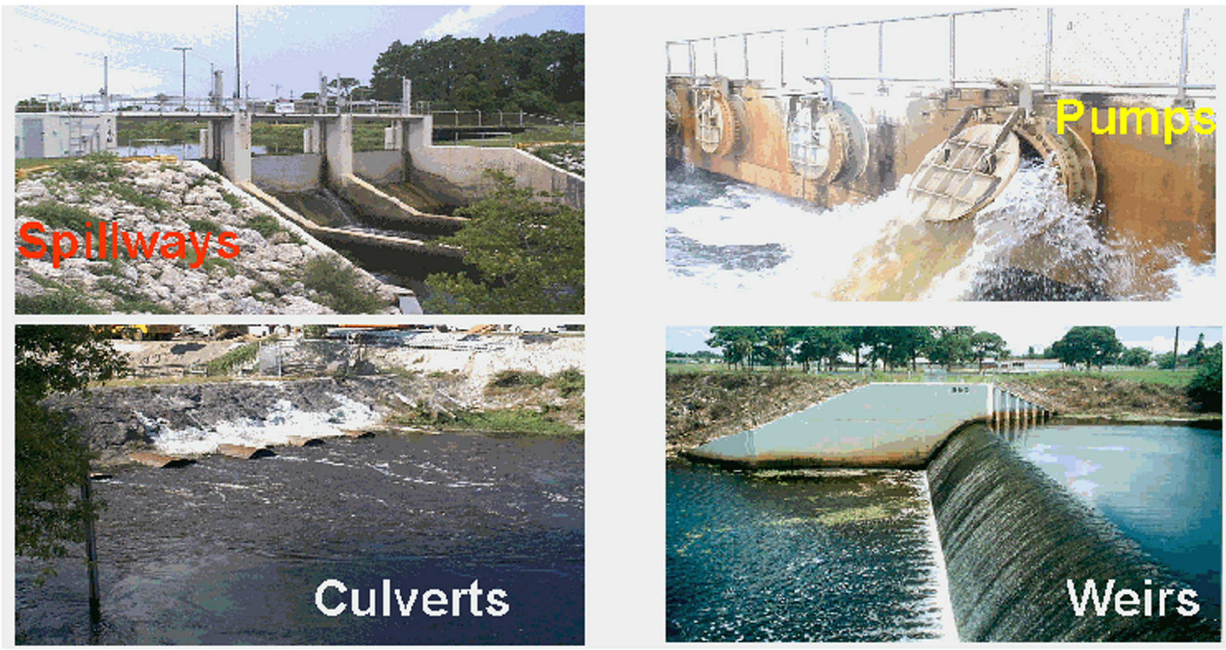
# EVALUATING AND IMPROVING FLOW DATA QUALITY USING STRIVE DATA AT WATER CONTROL STRUCTURES

**Volume I**




**By**

**Chandra Pathak, Lead Engineer**
**Manjiang Chen, Staff Engineer**

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**OPERATIONS AND HYDRO DATA MANAGEMENT DIVISION**
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**SOUTH FLORIDA WATER MANAGEMENT DISTRICT**

# EXECUTIVE SUMMARY


The South Florida Water Management District (District) is responsible for managing water resources in 16 counties within South Florida. The District operates 1,800 miles of canals and more than 400 water control structures. The agency is also responsible for collecting, validating, and archiving hydrological data including water level, water control structure operations, and flow.

As of March 2005, flow is computed by the District at 423 water control structures. These structures are comprised of culverts (58 percent), spillways (25 percent), pump stations (13 percent), and weirs (4 percent). In order to compute flow, the District determines static structure information from the “as-built” drawings of structures. The flow data are stored in DBHYDRO, the District’s hydrometeorologic database. However, this static structure information is often not of sufficient quality to compute flow accurately in certain hydraulic conditions and, in some cases, the information is erroneous or not up to date.

In 1999, the Structure Information Verification (STRIVE) project was initiated to evaluate and improve the quality of existing flow data at each water control structure. This project was established to verify static structure information (dimensions, elevations, entrance and outlet conditions, sedimentation, and other maintenance effects) collected from recent field topographic and geometric surveys. To date, the District has completed field surveys for 367 water control structures. The flow data for 168 of these structures have been computed and archived in DBHYDRO.

This study provides details of the methodology and principles of hydraulics used in computing, comparing, and analyzing the flow data at the water control structures. Among the surveyed structures, 83 culverts, 65 spillways, 16 pump stations, and 4 weirs are registered in DBHYDRO and flow data have been computed. For each structure, a new flow time series was computed from recently acquired static structure data under the STRIVE project. The new and existing flow datasets were compared and analyzed for each structure. Average monthly differences in new and existing flow data were greater than ±5 percent for 47 structures and the differences were less than ±5 percent for 121 structures. Data change procedures will be used prior to revising the historical flow data series in DBHYDRO if the new flow data are significantly different. The improved flow datasets for the historical period of record from this project will be stored in DBHYDRO, where appropriate.

The District has completed field surveys for 78 additional water control structures where flow data analysis using STRIVE data are needed. In addition, 177 structures will need to be surveyed in the next four to five years, and these structures will also require flow data analysis.

# TABLE OF CONTENTS

## Volume I

EXECUTIVE SUMMARY ........................................................................................................ i

TABLE OF CONTENTS............................................................................................... ……ii

LIST OF TABLES…….......................................................................................................iii

LIST OF FIGURES… ........................................................................................................ iv

LIST OF APPENDICES (Volume II)….................................................................................v

ACKNOWLEDGEMENTS.. ................................................................................................ vii

INTRODUCTION ……………………………………………………………………………..1

DATA COLLECTION…………………………………………………………………………3

FLOW COMPUTATIONS AND DATA ANALYSES……………………...….......................6

RESULTS………………………………………………………………………………….…..... 8

CONCLUSIONS…….……………………………………………….......................................28

RECOMMENDATIONS………………………………………………………………………… 29

REFERENCES..……..…………………………………………………………………………… 30

# LIST OF TABLES

Table 1. Percent flow difference between STRIVE and DBHYDRO data for culverts: average monthly difference less than 5%. ..........9

Table 2. Percent flow difference between STRIVE and DBHYDRO data for culverts: average monthly difference greater than 5%..........11

Table 3. Percent flow difference between STRIVE and DBHYDRO data for spillways: average monthly difference less than 5%. ..........12

Table 4. Percent flow difference between STRIVE and DBHYDRO data for spillways: average monthly difference greater than 5%..……..14

Table 5. Percent flow difference between STRIVE and DBHYDRO data for pump stations: average monthly difference less than 5%..........15

Table 6. Percent flow difference between STRIVE and DBHYDRO data for weirs: average monthly difference less than 5%..........15

Table 7. Percent flow difference between STRIVE and DBHYDRO data for weirs: average monthly difference greater than 5%. ……..........15

Table 8. Water control structures: survey completed and flow data analysis using STRIVE data is needed..........16

Table 9A. Water control structures: survey and flow data analysis are needed where stream gauging data are available……..19

Table 9B. Water control structures: survey and flow data analysis are needed where stream gauging data are not available……......21

# LIST OF FIGURES

Figure 1. Flow data computations at 423 District water control structures…..………………………….......4

Figure 2. Water control structures in STAs and C&SF system …………………………………………..…..4

Figure 3. Stream gauging data availability for water control structures……………………….………….5

Figure 4. Current status and future work effort for the STRIVE project……………………………….….5

Figure 5. Status of survey and flow data analysis for culverts ……..…………………...………………..26

Figure 6. Status of survey and flow data analysis for spillways ……………………………..…………..26

Figure 7. Status of survey and flow data analysis for pump stations……………………..……..……....27

Figure 8. Status of survey and flow data analysis for weirs…..…………………..……………………27

**Volume II**

## LIST OF APPENDICES

**Appendix A**: Standard survey sheet

A-C: Culvert……………………………………………………………………………………A-C_1

A-S: Spillway…………………………………………………………………………………A-S_1

A-P: Pump station……………………………………………………………………………A-P_1

A-W: Weir……………………………………………………………………………………A-W_1

**Appendix B**: STRIVE data for water control structures

B-C: Culvert………………………………………………………………………………….....B-C_1

B-S: Spillway…………………………………………………………………………………B-S_1

B-P: Pump station……………………………………………………………………………B-P_1

B-W: Weir……………………………………………………………………………………B-W_1

**Appendix C**: Structures data comparison between STRIVE and DBHYDRO

C-C: Culvert……………………………………………………………………………………C-C_1

C-S: Spillway…………………………………………………………………………………C-S_1

C-P: Pump station……………………………………………………………………………C-P_1

C-W: Weir……………………………………………………………………………………C-W_1

**Appendix D**: Flow data comparison between STRIVE and DBHYDRO

D-C: Culvert……………………………………………………………………………………D-C_1

D-S: Spillway…………………………………………………………………………………D-S_1

D-P: Pump station……………………………………………………………………………D-P_1

D-W: Weir……………………………………………………………………………………D-W_1

## Volume II

# LIST OF APPENDICES (Cont.)

**Appendix E**: Flow computations details

E-C: Culvert…………………………………………………………………………………………..E-C_1

E-S: Spillway…………………………………………………………………………………….....E-S_1

E-P: Pump station…………………………………………………………………………………..E-P_1

E-W: Weir…………………………………………………………………………………………E-W_1

**Appendix F**: Flow data analysis needed for survey completed water control structures

F-C: Culvert…………………………………………………………………………………………F-C_1

F-S: Spillway………………………………………………………………………………………F-S_1

F-P: Pump station…………………………………………………………………………………..F-P_1

F-W: Weir…………………………………………………………………………………………F-W_1

**Appendix G**: Remaining water control structures for surveying…………………………………………G_1

**Appendix H**: Water control structures surveyed but not available in DBHYDRO………..…...……..H_1

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# INTRODUCTION

## Background

The South Florida Water Management District (District) is responsible for protecting regional water supply resources and for alleviating flooding in 16 counties within South Florida. Within the Central and South Florida (C&SF) drainage system, the District manages about 1,800 miles of canals and levees and more than 400 water control structures. Extensive hydrological and structure operational data (e.g., water level and gate openings) are collected, validated, analyzed, and archived by the District to support its water management efforts.

In 1999, the Structure Information Verification (STRIVE) project was initiated to improve the quality of existing structure data and computed flow data at each water control structure. Because flow computations are based on both static and dynamic data available for each structure, the District has historically determined static structure information from the "as-built" drawings of structures. The flow data are stored in DBHYDRO, the District's hydrometeorologic database. However, these "as-built" drawings do not often meet accuracy and precision needed for flow computation purposes due to many site conditions, such as uneven weir perimeters, weed clogging, weed barriers, rebuilt and new constructions, and structure failures.

The STRIVE project was established to verify static structure information collected from field topographic and geometric surveys. The information is composed of dimensions, elevations, entrance and outlet conditions, sedimentation, and other maintenance effects. These structures consist of culverts, spillways, pump stations, and weirs. The District completed the topographic surveys for 367 water control structures over the last six years.

This report details the methodology and principles of hydraulics used in computation, comparison, and analysis of the flow data at 168 water control structures. For each structure, a new flow time series was computed from recently obtained static structure data under the STRIVE project. Differences in new and existing flow data were compared for the structures. The revised flow datasets for the historical period of record from this project will be stored in DBHYDRO, where appropriate. This project is important because it will substantially improve the accuracy and precision of flow data necessary for water budgets and water quality analyses that are used in various water resources projects at the District.

## Project Objectives

The goals and objectives of this project are to:

- verify the information relevant to the physical characteristics of the District's hydraulic structures.
- use the structure static data that are obtained from field surveys to improve computed flow data.
- systematically review and verify structure information.

## Scope of the Project

The scope of this project is to:

- compare STRIVE data with data in DBHYDRO currently used in computing flow.
- verify all inconsistencies at the structures using standard survey forms.
- assess the impact of the newly computed flow data on historical flows obtained from DBHYDRO using the FLOW computer program.
- revise static structure data in DBHYDRO, where warranted.
- use data change procedures (Akpoji et al., 2003) prior to revising the historical flow data series in DBHYDRO if the new flow data are significantly different.

# DATA COLLECTION

The STRIVE project is concerned with structure static data and has revealed inconsistencies between water control structure data in DBHYDRO and field measured topographic and geometric data. Site visits to structures have identified static data discrepancies that could lead to inaccurate flow computations. The structure data that were field verified include the descriptive parameters of structures: sill and invert elevations, gate types, gate shapes, gate dimensions, culvert types, culvert materials, etc. These parameters constitute the static structure data and are used in the District's FLOW computer program.

As of March 2005, the District computed flow at 423 water control structures registered in DBHYDRO. It should be noted that several water control structures are added every week at the District. Several structures that are under construction at Stormwater Treatment Areas 1 East and 3/4 (STA-1E and STA-3/4) are not included in this study. The 423 structures are grouped into culverts (58 percent), spillways (25 percent), pump stations (13 percent), and weirs (4 percent) (**Figure 1**). Approximately 45 percent of the water control structures are located in the STAs and 55 percent of these structures are located within the C&SF system (**Figure 2**). Only 56 percent of the structures have stream gauging data (**Figure 3**) that is used in calibrating and validating flow rating equations. Currently, the STRIVE project has completed surveying and flow data analysis for 168 water control structures (40 percent). Of the remaining structures, 78 (18 percent) have been surveyed but still require flow data analysis and 177 (42 percent) require surveying and flow data analysis (**Figure 4**).

After collecting the field data, the District's professional surveyors record the data on a standard survey data sheet (see Appendix A). The survey data sheets are signed, sealed, and submitted to the STRIVE project manager, Mr. Howard Ehmke.

The topographic surveys were performed to National Geodetic Survey's (NGS) third order closure standard [defined as (0.05 ft) * √ (Distance in Miles) for elevation data]. All elevations measured at the water control structures are provided in North American Vertical Datum (NAVD) 1988 and National Geodetic Vertical Datum (NGVD) 1929.

Prior to performing the field surveys, the surveyors compared the data values from "as-built" drawings, structure books, and design drawings. After proper examination for consistency and errors, the surveyed data for all structure parameters was entered into STRIVE tables using Microsoft Excel. All data for a given structure were reviewed and revised by the responsible engineer for consistency and accuracy.

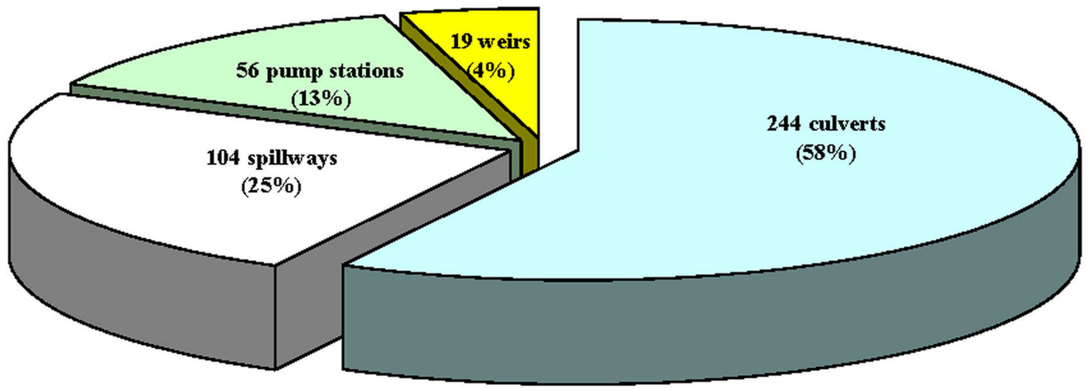


**Figure 1.** Flow data computations at the 423 District water control structures, as of March 2005.

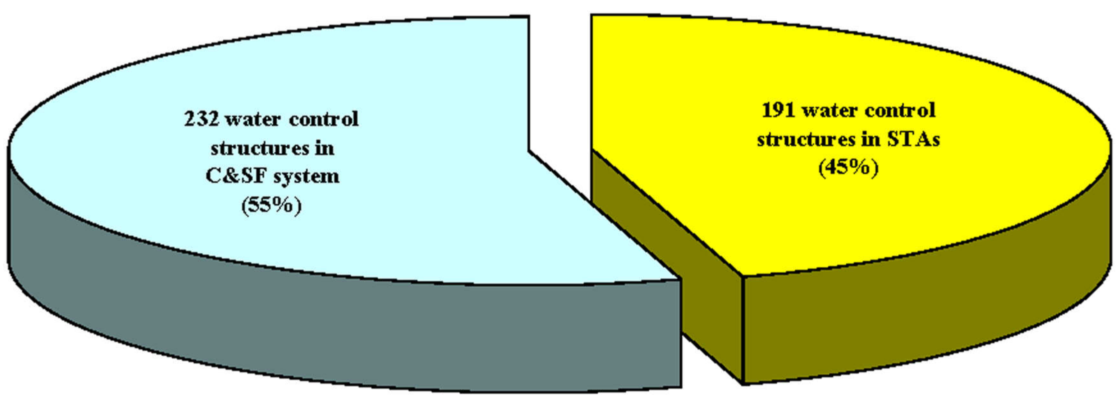


**Figure 2.** Water control structures in the STAs and C&SF system, as of March 2005.

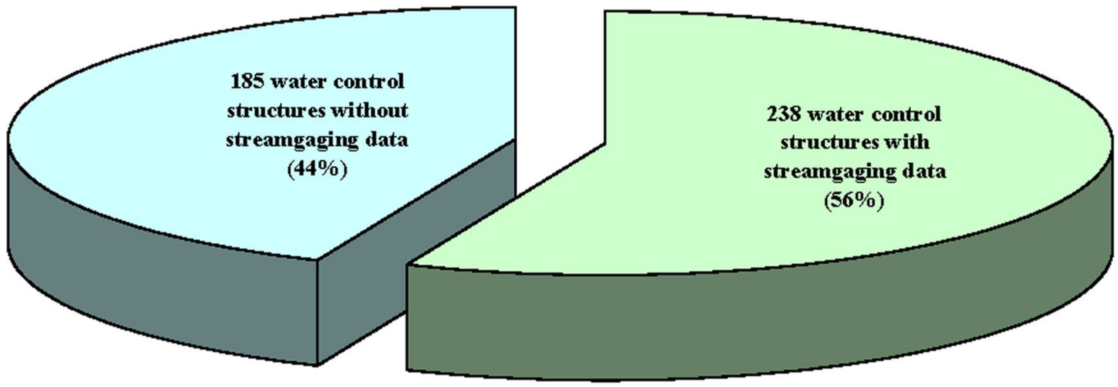


**Figure 3.** Stream gauging data availability for water control structures, as of March 2005.

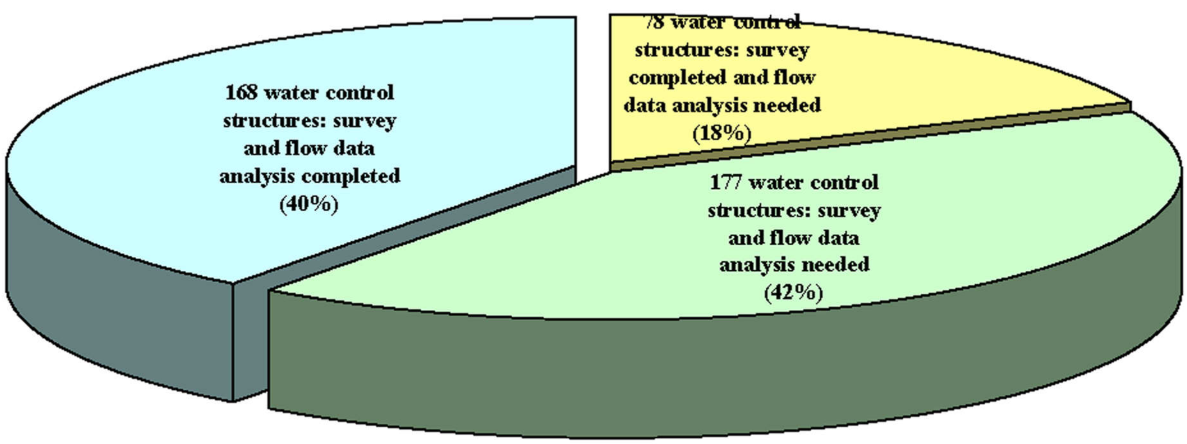


**Figure 4.** Current status and future work effort for the STRIVE project, as of March 2005.

# FLOW COMPUTATIONS AND DATA ANALYSES

## Flow Computations

Flow data computations at the water control structures require a. static structure data; b. three dynamic data sets that include upstream stage, downstream stage and structure operation data and c. hydraulic flow equations. Errors in these three areas result in errors in computed flow values. This study focused on use of the improved static structure information in estimating flow data. The two other data groups, as noted above, are not evaluated in the study. However, they remain critical in improving the accuracy of the flow data as well.

The static structure data are determined, in the majority of the cases, from the "as-built" drawings of the structure. Three dynamic data that include upstream stage, downstream stage and structure operation data are obtained from sensor instruments in the field located within the vicinity of the structure.

Flow equations used in the District are assembled from various sources based on the structure type (culvert, spillway, pump station, weir) and flow regime (Ansar and Alexis, 2003). These equations are used in the FLOW computer program that was written in FORTRAN.

Culvert flow computations are based on three types of flow conditions: full-pipe flow, orifice flow, and open channel flow. Full-conduit flow is subdivided into two subtypes of flow conditions depending on whether the inlet is submerged or free. Orifice flow is similarly subdivided into two subtypes depending on whether the barrel is partially filled or completely full. Open channel flow is subdivided into three subtypes depending on whether critical flow occurs at the inlet or at the outlet, or whether subcritical flow occurs throughout the barrel under tailwater control. Culvert flow equations were developed from hydraulic principles by Fan (1985).

The U.S. Army Corps of Engineers derived the flow equations from small-scale model testing model of C & SF spillways (Ansar and Alexis, 2003). Spillway flow is classified into five types: controlled free, controlled submerged, uncontrolled free, uncontrolled submerged and over-the-top flows.

The District subdivides spillways into three cases for flow computations:

- Case 1: The flow rate is obtained from a standard spillway equation with the discharge coefficient set equal to a constant for each flow condition.
- Case 2: The flow rate is computed from a standard spillway equation with a variable discharge coefficient at each flow condition.
- Case 3: The flow rate is obtained from a non-standardized equation derived mostly from regression analysis of the flow measurements.

Flows at pump stations are modeled based on pump curves, which define the flow rate as a polynomial function of the head difference. There are eight cases for flow computations. Cases 1 and 5 are used at constant speed pumps, where flow is computed using a third order polynomial fitting of the head difference (pump head) between upstream and downstream stages. Cases 2 and 4 are used at highly variable speed pumps, where flow is computed using a two-variable polynomial fitting of the pumping head and the engine speed of the pump. Case 3 is used at variable speed pumps, where flow is obtained from an interpolation between an upper and lower discharge curves that are given by third order polynomials of the pumping head, as in Cases 1 and 5. Case 6 is developed for the variable speed pumps, where the flow is computed as a function of the pumping head and the pump engine speed. In Case 7, pump affinity laws are used to predict the discharge. Case 8 is used to generalize variable and constant speed pumps in order to simplify computations.

Weirs are classified into three major categories: ogee, trapezoidal, and variable weirs for flow computations. A free weir equation is used to compute free flows; however, Villemonte's equation is used to compute submerged flows. For trapezoidal weirs, combinations of V-notch and rectangular weir flows are used to compute the discharge. For variable weirs, a distinction is made between sharp-crested and broad-crested weir flows based on the ratio of the headwater depth above sill, and the crest width in the direction of the flow.

**Data Analyses**

In this study, flow data were computed using the FLOW computer program for two sets of structure static data that were obtained from DBHYDRO and the STRIVE project. Subsequently, the two sets of flow data were compared and analyzed.

Data analysis was performed on the calculated historical flow data at each of the 168 water control structures. Mean daily flow data were computed for each water control structure using static structure data from DBHYDRO and STRIVE. The period of record for the flow data varied up to 10 years depending upon availability of historical data for each structure. The daily difference in mean daily flow data between DBHYDRO and STRIVE were computed for each structure and for the period of record. Subsequently, average monthly differences were computed from daily differences.

In addition, for each structure, the percent of records where the flow differences were greater than ±5 percent was computed. This percentage was obtained by dividing the number of flow days when flow differences were greater than ± 5 percent by the total number of flow days.

# RESULTS

A total of 367 water control structures (225 culverts, 90 spillways, 30 pump stations, and 22 weirs) were surveyed under the STRIVE project. Among these structures, 83 culverts, 65 spillways, 16 pump stations, and 4 weirs are registered in DBHYDRO and had flow data computed by the District. However, 15 culverts and 10 spillways were registered in DBHYDRO but flow data were not computed. Of these structures, 62 culverts, 63 spillways, 15 pump stations, and 3 weirs had stream gauging data.

Analysis was performed on the calculated historical flow data to determine impacts to the 168 water control structures. The average, maximum and minimum monthly differences in percent were computed for each structure and are presented in **Tables 1** through **7.** These tables were grouped based on structure type and percent of average monthly differences that are less than or greater than ±5 percent. The static structure information for each water control structure is presented in Appendices B through D. Appendix E summarizes structure information and computed flow differences between DBHYDRO and STRIVE.

Average monthly differences in new and existing flow data were less than ±5 percent for 121 water control structures and the differences were greater than ±5 percent for 47 water control structures. Average monthly differences in new and existing flow data were less than and greater than ±5 percent for 56 and 27 culverts, respectively. For spillways, average monthly differences were less than and greater than ±5 percent for 47 and 18 spillways, respectively. Whereas, average monthly differences were less than ±5 percent for all 16 pump stations; and the differences were less than and greater than ±5 percent for 2 weirs. For four culverts, three spillways and one pump station, average monthly flow differences were less than ±5 percent and percent records were greater than 20 percent.

Flow data for 168 structures was computed and compared. Field surveying for 78 structures was completed but flow data analysis is needed for these structures. Currently, 177 structures will need to be surveyed. Thirty-five of these structures have stream gauging data. These structures are identified in **Tables 8**, **9A**, and **9B**.

**Figures 5** through **8** show the current status of work completed and work remaining for culverts, spillways, pump stations, and weirs, respectively. The surveyed structures static data are presented in Appendix F. Appendix G contains a list of structures that require surveying. Appendix H includes all water control structures that were surveyed but they are not listed in DBHYDRO database.

In next four to five years, surveying will be needed on the remaining 177 structures. The structure static data in DBHYDRO will be revised, as appropriate, and then the new flow data and historical flow data will be compared. If new flow data is significantly different, then data change procedures (Akpoji et al., 2003) will be used prior to revising the historical flow data series in DBHYDRO.

**Table 1.** Percent flow difference between STRIVE and DBHYDRO data for culverts: average monthly difference less than 5%.

| Station Name | Monthly Difference | | | % of Records have difference > 5 % |
|---|---|---|---|---|
| | Ave % | Max % | Min % | |
| S143_C | 0.01 | 0.09 | 0.00 | 0.00 |
| S197_C | 0.02 | 1.20 | 0.00 | 0.05 |
| G344B_C | 0.02 | 0.79 | 0.00 | 0.05 |
| S30_C | 0.04 | 7.61 | 0.00 | 0.20 |
| S343A_C | 0.04 | 1.30 | 0.00 | 0.15 |
| S344_C | 0.04 | 0.91 | 0.00 | 0.00 |
| G344C_C | 0.04 | 1.00 | 0.00 | 0.10 |
| G344D_C | 0.04 | 1.33 | 0.00 | 0.20 |
| G34_C | 0.06 | 2.85 | 0.00 | 0.51 |
| S121_C | 0.07 | 5.55 | 0.00 | 0.46 |
| S337_C | 0.07 | 9.94 | 0.00 | 0.34 |
| S336_C | 0.08 | 1.85 | 0.00 | 0.00 |
| S151_C | 0.09 | 11.80 | 0.00 | 0.49 |
| G119_C | 0.11 | 1.54 | 0.00 | 0.00 |
| S10E_C | 0.22 | 6.39 | 0.00 | 2.18 |
| S175_C | 0.24 | 3.58 | 0.00 | 1.20 |
| S343B_C | 0.36 | 30.39 | 0.00 | 0.36 |
| G94C_C | 0.38 | 0.91 | 0.00 | 0.00 |
| G204_C | 0.40 | 16.43 | 0.00 | 5.06 |
| G72_C | 0.43 | 14.85 | 0.00 | 1.77 |
| G58_C | 0.52 | 19.39 | 0.00 | 1.46 |
| S169_C | 0.59 | 12.26 | 0.00 | 1.00 |
| G327A | 0.61 | 4.15 | 0.00 | 3.93 |
| S58_C | 0.71 | 31.01 | 0.00 | 2.28 |
| S142_C | 0.73 | 13.36 | 0.00 | 2.40 |
| G304J_C | 0.74 | 9.00 | 0.00 | 1.85 |
| G206_C | 0.84 | 10.53 | 0.00 | 7.32 |
| S195_C | 1.03 | 13.10 | 0.00 | 8.54 |
| S338_C | 1.11 | 3.21 | 0.00 | 0.52 |
| S154_C | 1.48 | 36.44 | 0.00 | 2.26 |
| S178_C | 1.56 | 29.35 | 0.00 | 7.64 |

*: % of Records that are greater than 20 percent.

**Table 1.** Continued.

| Station Name | Monthly Difference Ave % | Max % | Min % | % of Records have difference > 5 % |
|---|---|---|---|---|
| G108_C | 1.68 | 26.31 | 0.00 | 1.63 |
| G96_C | 1.77 | 18.90 | 0.00 | 3.15 |
| S146_C | 1.80 | 14.32 | 0.00 | 17.41 |
| S120_C | 1.82 | 33.80 | 0.00 | 2.60 |
| S150_C | 1.86 | 47.20 | 0.00 | 5.66 |
| S144_C | 1.98 | 43.00 | 0.00 | 11.50 |
| G69_C | 1.98 | 58.56 | 0.00 | 6.87 |
| G607 | 2.13 | 11.97 | 0.16 | 11.71 |
| G88_C | 2.25 | 12.02 | 0.00 | 19.63 |
| G304I_C | 2.62 | 15.49 | 0.00 | 8.37 |
| S173_C | 2.79 | 50.49 | 0.00 | 14.06 |
| S13A_C | 2.85 | 64.18 | 0.00 | 12.08 |
| S145_C | 2.87 | 11.08 | 0.00 | 24.51* |
| G304D_C | 2.87 | 18.50 | 0.00 | 9.33 |
| G304G_C | 2.90 | 19.20 | 0.00 | 7.23 |
| G304A_C | 3.03 | 20.23 | 0.00 | 7.46 |
| G304C_C | 3.17 | 25.13 | 0.00 | 11.80 |
| G211_C | 3.34 | 99.69 | 0.00 | 5.05 |
| G136_C | 3.77 | 7.69 | 0.00 | 51.46* |
| G150_C | 3.94 | 32.36 | 0.00 | 15.94 |
| G304F_C | 3.99 | 22.30 | 0.00 | 8.41 |
| G304E_C | 4.06 | 39.37 | 0.00 | 11.55 |
| G135_C | 4.53 | 85.68 | 0.00 | 40.92* |
| G304H_C | 4.65 | 33.27 | 0.00 | 9.00 |
| S38C_C | 4.75 | 8.08 | 0.00 | 66.60* |

*: % of Records that are greater than 20 percent.

**Table 2.** Percent flow difference between STRIVE and DBHYDRO data for culverts: average monthly difference greater than 5%.

| Station Name | Monthly Difference Ave % | Max % | Min % | % of Records have difference > 5 % |
|---|---|---|---|---|
| S34_C | 6.68 | 56.17 | 0.00 | 24.39* |
| G134_C | 6.84 | 24.82 | 0.00 | 51.29* |
| G306E | 6.98 | 22.18 | 0.00 | 34.91* |
| G306J | 7.03 | 20.21 | 0.00 | 38.51* |
| G306D | 7.09 | 23.78 | 0.00 | 35.00* |
| S194_C | 7.53 | 51.16 | 0.00 | 31.10* |
| G306B | 7.62 | 22.21 | 0.00 | 37.28* |
| G306A | 7.67 | 22.20 | 0.00 | 37.54* |
| G306H | 7.74 | 22.15 | 0.00 | 37.98* |
| G304B | 7.93 | 44.37 | 0.00 | 7.26 |
| G306G | 8.10 | 22.12 | 0.00 | 39.04* |
| G306I | 8.18 | 22.15 | 0.00 | 39.39* |
| G306C | 8.36 | 26.50 | 0.00 | 35.44* |
| G354A_C | 9.44 | 100.00 | 0.00 | 39.90* |
| G354B_C | 9.44 | 100.00 | 0.00 | 39.90* |
| S124_C | 9.69 | 81.51 | 0.00 | 34.66* |
| S57_C | 9.76 | 57.70 | 0.00 | 31.13* |
| S196_C | 9.83 | 54.93 | 0.00 | 30.78* |
| G354C_C | 11.14 | 99.51 | 0.00 | 40.88* |
| S31_C | 11.38 | 88.27 | 0.00 | 20.51* |
| G306F | 11.87 | 36.21 | 0.00 | 37.19* |
| G151_C | 13.11 | 50.01 | 0.00 | 65.90* |
| S32_C | 15.75 | 96.14 | 0.00 | 34.09* |
| S47B_C | 17.79 | 32.97 | 0.00 | 98.18* |
| G92_C | 18.65 | 45.48 | 0.00 | 80.83* |
| S25_C | 19.42 | 86.95 | 0.00 | 42.01* |
| S38_C | 26.03 | 89.16 | 0.00 | 48.35* |

*: % of Records that are greater than 20 percent.

**Table 3.** Percent flow difference between STRIVE and DBHYDRO data for spillways: average monthly difference less than 5%.

| Station Name | Monthly Difference | | | % of Records have difference > 5 % |
|---|---|---|---|---|
| | Ave. % | Max. % | Min. % | |
| S118_S | 0.03 | 0.99 | 0.00 | 0.05 |
| S166_S | 0.04 | 0.81 | 0.00 | 0.03 |
| S29_S | 0.06 | 3.65 | 0.00 | 0.23 |
| S68_S | 0.07 | 1.57 | 0.00 | 0.09 |
| G338_C | 0.07 | 0.33 | 0.00 | 0.00 |
| S179_S | 0.09 | 1.80 | 0.00 | 0.38 |
| S191_S | 0.10 | 3.22 | 0.00 | 0.79 |
| S82_S | 0.12 | 0.21 | 0.00 | 0.00 |
| S33_S | 0.15 | 13.35 | 0.00 | 0.28 |
| S177_S | 0.16 | 3.72 | 0.00 | 0.21 |
| S119_S | 0.17 | 7.94 | 0.00 | 0.16 |
| S22_S | 0.17 | 3.67 | 0.00 | 0.49 |
| S28_S | 0.18 | 5.22 | 0.00 | 0.62 |
| G339_S | 0.21 | 3.33 | 0.00 | 0.23 |
| S167_S | 0.28 | 2.34 | 0.00 | 0.69 |
| S11A_C | 0.28 | 2.34 | 0.00 | 0.30 |
| S165_S | 0.31 | 2.84 | 0.00 | 0.41 |
| G301_S | 0.47 | 1.94 | 0.00 | 0.20 |
| S20_S | 0.48 | 38.67 | 0.00 | 2.48 |
| S334_S | 0.52 | 2.76 | 0.00 | 0.07 |
| S27_S | 0.58 | 0.73 | 0.00 | 0.00 |
| S190_S | 0.64 | 6.77 | 0.00 | 2.84 |
| S123_S | 0.70 | 3.00 | 0.00 | 0.12 |
| S174_S | 0.81 | 3.94 | 0.00 | 0.28 |
| S155_S | 0.93 | 1.97 | 0.00 | 0.05 |
| S21_S | 1.14 | 80.10 | 0.00 | 2.08 |
| G93 | 1.29 | 26.46 | 0.00 | 1.00 |
| S40_S | 1.35 | 32.39 | 0.00 | 1.78 |
| S21A_S | 1.41 | 31.97 | 0.00 | 5.79 |
| S72_S | 1.44 | 11.49 | 0.00 | 3.99 |

*: % of Records that are greater than 20 percent..

**Table 3.** Continued.

| Station Name | Monthly Difference | | | % of Records have difference > 5 % |
|---|---|---|---|---|
| | Ave. % | Max. % | Min. % | |
| S75_S | 1.69 | 2.15 | 0.00 | 0.00 |
| S70_S | 1.84 | 6.37 | 0.00 | 1.06 |
| S41_S | 1.93 | 39.69 | 0.00 | 2.99 |
| S20G_S | 1.94 | 30.46 | 0.00 | 6.64 |
| S26_S | 2.34 | 8.92 | 0.00 | 0.13 |
| S335_S | 2.73 | 33.75 | 0.00 | 0.97 |
| S25B_S | 2.77 | 6.40 | 0.00 | 1.99 |
| G57_S | 2.96 | 23.80 | 0.00 | 0.78 |
| S97_S | 3.09 | 20.07 | 0.00 | 3.14 |
| G302_S | 3.22 | 10.15 | 0.00 | 23.46* |
| G54_S | 3.44 | 5.71 | 0.00 | 30.81* |
| S71_S | 3.71 | 83.82 | 0.00 | 4.48 |
| S148_S | 3.82 | 27.91 | 0.00 | 9.68 |
| S37A_S | 4.14 | 93.59 | 0.00 | 3.92 |
| S333_S | 4.24 | 70.03 | 0.00 | 3.62 |
| S59_S | 4.35 | 59.65 | 0.00 | 11.23 |
| S36_S | 4.51 | 33.20 | 0.00 | 50.82* |

*: % of Records that are greater than 20 percent.

**Table 4.** Percent flow difference between STRIVE and DBHYDRO data for spillways: average monthly difference greater than 5%.

| Station Name | Monthly Difference | | | % of Records have difference > 5 % |
|---|---|---|---|---|
| | Ave. % | Max. % | Min. % | |
| S155A_S | 5.86 | 20.87 | 0.00 | 83.57* |
| G303_S | 6.01 | 11.50 | 0.00 | 54.08* |
| S20F_S | 6.51 | 10.26 | 0.00 | 79.28* |
| S49_S | 7.16 | 55.11 | 0.00 | 7.43 |
| S83_S | 8.28 | 49.55 | 0.00 | 9.81 |
| G56_S | 8.68 | 18.98 | 0.00 | 72.38* |
| S176_S | 9.62 | 27.40 | 0.00 | 43.11* |
| S18C_S | 9.79 | 24.65 | 0.00 | 38.83* |
| S46_S | 9.95 | 76.45 | 0.00 | 33.18* |
| S47D_S | 15.29 | 100.00 | 0.00 | 24.43* |
| S99_S | 16.22 | 76.64 | 0.00 | 21.00* |
| S84_S | 31.81 | 93.92 | 0.00 | 54.55* |
| S44_S | 48.67 | 100.00 | 3.82 | 88.05* |
| S37B_S | 53.20 | 100.00 | 0.00 | 75.76* |
| S354_S | 641.92 | 17439.00 | 0.00 | 18.55 |
| S351_S | 1042.11 | 24212.98 | 0.00 | 29.05* |
| S352_S | 2605.18 | 173010.72 | 0.00 | 44.62* |
| S39_S | 4494.81 | 96404.53 | 0.00 | 55.78* |

*: % of Records that are greater than 20 percent.

**Table 5.** Percent flow difference between STRIVE and DBHYDRO data for pump stations: average monthly difference less than 5%.

| Station Name | Monthly Difference | | | % of Records have difference > 5 % |
|---|---|---|---|---|
| | Ave. % | Max. % | Min. % | |
| S332D_P | 0.00 | 0.00 | 0.00 | 0.00 |
| S127_P | 0.00 | 0.00 | 0.00 | 0.00 |
| S2_P | 0.00 | 0.00 | 0.00 | 0.00 |
| S3_P | 0.00 | 0.03 | 0.00 | 0.00 |
| S4_P | 0.00 | 0.00 | 0.00 | 0.00 |
| S135_P | 0.00 | 0.08 | 0.00 | 0.03 |
| G-600_P | 0.01 | 0.34 | 0.00 | 0.04 |
| S6_P | 0.02 | 3.00 | 0.00 | 0.03 |
| S131_P | 0.05 | 3.65 | 0.00 | 0.48 |
| S129_P | 0.06 | 4.02 | 0.00 | 0.75 |
| S140_P | 0.63 | 54.33 | 0.00 | 1.77 |
| G409_P | 0.65 | 6.93 | 0.00 | 1.98 |
| S332_P | 1.53 | 9.68 | 0.00 | 13.30 |
| S133_P | 3.46 | 59.89 | 0.00 | 4.24 |
| S331_P | 4.68 | 10.74 | 0.00 | 45.32* |
| G123_P | 4.76 | 99.99 | 0.00 | 16.35 |

**Table 6.** Percent flow difference between STRIVE and DBHYDRO data for weirs: average monthly difference less than 5%.

| Station Name | Monthly Difference | | | % of Records have difference > 5 % |
|---|---|---|---|---|
| | Ave. % | Max. % | Min. % | |
| S50_S | 0.41 | 4.73 | 0.00 | 1.08 |
| S141_W | 2.77 | 21.45 | 0.00 | 20.87* |

**Table 7.** Percent flow difference between STRIVE and DBHYDRO data for weirs: average monthly difference greater than 5%.

| Station Name | Monthly Difference | | | % of Records have difference > 5 % |
|---|---|---|---|---|
| | Ave. % | Max. % | Min. % | |
| G155_W | 7.46 | 15.18 | 0.00 | 65.78* |
| S48_S | 27.27 | 79.42 | 0.00 | 80.13* |

*: % of Records that are greater than 20 percent.

**Table 8.** Water control structures: survey completed and flow data analysis using STRIVE data is needed.

| Station Name | Structure Type | STA Site | Stream Gauging Data |
|---|---|---|---|
| CV5 | Culvert | No | No |
| G205_C | Culvert | No | No |
| S380_C | Culvert | No | No |
| S38A_C | Culvert | No | No |
| S12A_S | Spillway | No | No |
| S12B_S | Spillway | No | No |
| S12C_S | Spillway | No | No |
| S12D_S | Spillway | No | No |
| S5AS_S | Spillway | No | No |
| G258_C | Culvert | Yes | No |
| G259_C | Culvert | Yes | No |
| G305G_C | Culvert | Yes | No |
| G305N_C | Culvert | Yes | No |
| G331G_C | Culvert | Yes | No |
| G393A_C | Culvert | Yes | No |
| G393C_C | Culvert | Yes | No |
| G349B_P | Pump | Yes | No |
| G350B_P | Pump | Yes | No |
| CULV5A_C | Culvert | No | Yes |
| PC17A_C | Culvert | No | Yes |
| G357_C | Culvert | No | Yes |
| S5AE_C | Culvert | No | Yes |
| S5AW_C | Culvert | No | Yes |
| G404_P | Pump | No | Yes |
| S13_P | Pump | No | Yes |
| S236_P | Pump | No | Yes |
| GORDY_S | Spillway | No | Yes |
| S13_S | Spillway | No | Yes |
| S339_S | Spillway | No | Yes |
| S61_S | Spillway | No | Yes |
| S63_S | Spillway | No | Yes |
| S63A_S | Spillway | No | Yes |

**Table 8.** Continued.

| Station Name | Structure Type | STA Site | Stream Gauging Data |
|---|---|---|---|
| S65E_S | Spillway | No | Yes |
| C18W_W | Weir | No | Yes |
| G329A_C | Culvert | Yes | Yes |
| G329B_C | Culvert | Yes | Yes |
| G329C_C | Culvert | Yes | Yes |
| G329D_C | Culvert | Yes | Yes |
| G330A_C | Culvert | Yes | Yes |
| G330B_C | Culvert | Yes | Yes |
| G330C_C | Culvert | Yes | Yes |
| G330D_C | Culvert | Yes | Yes |
| G330E_C | Culvert | Yes | Yes |
| G331A_C | Culvert | Yes | Yes |
| G331B_C | Culvert | Yes | Yes |
| G331C_C | Culvert | Yes | Yes |
| G331D_C | Culvert | Yes | Yes |
| G331E_C | Culvert | Yes | Yes |
| G331F_C | Culvert | Yes | Yes |
| G333A_C | Culvert | Yes | Yes |
| G333B_C | Culvert | Yes | Yes |
| G333C_C | Culvert | Yes | Yes |
| G333D_C | Culvert | Yes | Yes |
| G333E_C | Culvert | Yes | Yes |
| G342A_C | Culvert | Yes | Yes |
| G342B_C | Culvert | Yes | Yes |
| G342C_C | Culvert | Yes | Yes |
| G342D_C | Culvert | Yes | Yes |
| G344A_C | Culvert | Yes | Yes |
| G393B_C | Culvert | Yes | Yes |
| G406_C | Culvert | Yes | Yes |
| G251_P | Pump | Yes | Yes |
| G310_P | Pump | Yes | Yes |
| G328_P | Pump | Yes | Yes |

**Table 8.** Continued.

| Station Name | Structure Type | STA Site | Stream Gauging Data |
|---|---|---|---|
| G335_P | Pump | Yes | Yes |
| G337_P | Pump | Yes | Yes |
| G349A_P | Pump | Yes | Yes |
| G350A_P | Pump | Yes | Yes |
| S8_P | Pump | Yes | Yes |
| G300_S | Spillway | Yes | Yes |
| G308_S | Spillway | Yes | Yes |
| G309_S | Spillway | Yes | Yes |
| G332_S | Spillway | Yes | Yes |
| G334_S | Spillway | Yes | Yes |
| S8_S | Spillway | Yes | Yes |
| G601 | Weir | Yes | Yes |
| G602 | Weir | Yes | Yes |
| G603 | Weir | Yes | Yes |

**Table 9A.** Water control structures: survey and flow data analysis are needed where stream gauging data are available.

| Station Name | Structure Type | STA Site |
|---|---|---|
| S129_C | Culvert | No |
| S5AX_C | Culvert | No |
| G200A_P | Pump | No |
| G200B_P | Pump | No |
| G201_P | Pump | No |
| G207 | Pump | No |
| G208 | Pump | No |
| S9_P | Pump | No |
| S9A_P | Pump | No |
| COCO1_S | Spillway | No |
| S140_S | Spillway | No |
| S308_S | Spillway | No |
| S340_S | Spillway | No |
| S60_S | Spillway | No |
| S62_S | Spillway | No |
| S65_S | Spillway | No |
| S65A_S | Spillway | No |
| S65B_S | Spillway | No |
| S65C_S | Spillway | No |
| S65D_S | Spillway | No |
| S65NEW_S | Spillway | No |
| S77_S | Spillway | No |
| S78_S | Spillway | No |
| S79_S | Spillway | No |
| S80_S | Spillway | No |
| FAKA | Weir | No |
| LNHRT_W | Weir | No |
| WEIR1_W | Weir | No |
| WFEED_W | Weir | No |

**Table 9A.** Continued.

| Station Name | Structure Type | STA Site |
|---|---|---|
| G250_P | Pump | Yes |
| G370_P | Pump | Yes |
| G410_P | Pump | Yes |
| S5A_P | Pump | Yes |
| S7_P | Pump | Yes |
| S7_S | Spillway | Yes |

**Table 9B.** Water control structures: survey and flow data analysis are needed where stream gauging data are not available.

| Station Name | Structure Type | STA Site |
|---|---|---|
| BONEY.SC_C | Culvert | No |
| G402A_C | Culvert | No |
| G402B_C | Culvert | No |
| G402C_C | Culvert | No |
| G402D_C | Culvert | No |
| G74_C | Culvert | No |
| G75_C | Culvert | No |
| G76_C | Culvert | No |
| G86N_C | Culvert | No |
| G86S_C | Culvert | No |
| LETTC_C | Culvert | No |
| NUBBC_C | Culvert | No |
| S127_C | Culvert | No |
| S135_C | Culvert | No |
| S235_C | Culvert | No |
| S342_C | Culvert | No |
| S65AX_C | Culvert | No |
| S65BX1_C | Culvert | No |
| S65BX2_C | Culvert | No |
| S65CX_C | Culvert | No |
| S65DX_C | Culvert | No |
| S9XN_C | Culvert | No |
| S9XS_C | Culvert | No |
| SHING.PE | Culvert | No |
| SHING.PN | Culvert | No |
| SHING.SS | Culvert | No |
| ACME1 | Pump | No |
| ACME2 | Pump | No |
| EBPS3_P | Pump | No |
| ESPS2_P | Pump | No |
| G210_P | Pump | No |
| S25B_P | Pump | No |

**Table 9B.** Continued.

| Station Name | Structure Type | STA Site |
|---|---|---|
| S332B_P | Pump | No |
| S332B1_P | Pump | No |
| S332B2_P | Pump | No |
| COCO2_S | Spillway | No |
| COCO3_S | Spillway | No |
| G160_S | Spillway | No |
| S178_S | Spillway | No |
| BONEY.SW_W | Weir | No |
| COCO1_W | Weir | No |
| COCO3_W | Weir | No |
| S178_W | Weir | No |
| S59WEIR_W | Weir | No |
| WEIR2_W | Weir | No |
| WEIR3_W | Weir | No |
| G255A_C | Culvert | Yes |
| G255B_C | Culvert | Yes |
| G256_C | Culvert | Yes |
| G345_C | Culvert | Yes |
| G354_C | Culvert | Yes |
| G374A_C | Culvert | Yes |
| G374B_C | Culvert | Yes |
| G374C_C | Culvert | Yes |
| G374D_C | Culvert | Yes |
| G374E_C | Culvert | Yes |
| G374F_C | Culvert | Yes |
| G375A_C | Culvert | Yes |
| G375B_C | Culvert | Yes |
| G375C_C | Culvert | Yes |
| G375D_C | Culvert | Yes |
| G375E_C | Culvert | Yes |
| G375F_C | Culvert | Yes |
| G376A_C | Culvert | Yes |

**Table 9B.** Continued.

| Station Name | Structure Type | STA Site |
|---|---|---|
| G376B_C | Culvert | Yes |
| G376C_C | Culvert | Yes |
| G376D_C | Culvert | Yes |
| G376E_C | Culvert | Yes |
| G376F_C | Culvert | Yes |
| G377A_C | Culvert | Yes |
| G377B_C | Culvert | Yes |
| G377C_C | Culvert | Yes |
| G377D_C | Culvert | Yes |
| G377E_C | Culvert | Yes |
| G378A_C | Culvert | Yes |
| G378B_C | Culvert | Yes |
| G378C_C | Culvert | Yes |
| G378D_C | Culvert | Yes |
| G378E_C | Culvert | Yes |
| G379A_C | Culvert | Yes |
| G379B_C | Culvert | Yes |
| G379C_C | Culvert | Yes |
| G379D_C | Culvert | Yes |
| G379E_C | Culvert | Yes |
| G380A_C | Culvert | Yes |
| G380B_C | Culvert | Yes |
| G380C_C | Culvert | Yes |
| G380D_C | Culvert | Yes |
| G380E_C | Culvert | Yes |
| G380F_C | Culvert | Yes |
| G381A_C | Culvert | Yes |
| G381B_C | Culvert | Yes |
| G381C_C | Culvert | Yes |
| G381D_C | Culvert | Yes |
| G381E_C | Culvert | Yes |
| G381F_C | Culvert | Yes |

**Table 9B.** Continued.

| Station Name | Structure Type | STA Site |
|---|---|---|
| G382A_C | Culvert | Yes |
| G382B_C | Culvert | Yes |
| G383_C | Culvert | Yes |
| G393_C | Culvert | Yes |
| G600C_C | Culvert | Yes |
| S363A_C | Culvert | Yes |
| S363B_C | Culvert | Yes |
| S363C_C | Culvert | Yes |
| S364A_C | Culvert | Yes |
| S364B_C | Culvert | Yes |
| S364C_C | Culvert | Yes |
| S365A_C | Culvert | Yes |
| S365B_C | Culvert | Yes |
| S366A_C | Culvert | Yes |
| S366B_C | Culvert | Yes |
| S366C_C | Culvert | Yes |
| S366D_C | Culvert | Yes |
| S366E_C | Culvert | Yes |
| S367A_C | Culvert | Yes |
| S367B_C | Culvert | Yes |
| S367C_C | Culvert | Yes |
| S367D_C | Culvert | Yes |
| S367E_C | Culvert | Yes |
| S368A_C | Culvert | Yes |
| S368B_C | Culvert | Yes |
| S368C_C | Culvert | Yes |
| S368D_C | Culvert | Yes |
| S368E_C | Culvert | Yes |
| S369A_C | Culvert | Yes |
| S369B_C | Culvert | Yes |
| S369C_C | Culvert | Yes |
| S369D_C | Culvert | Yes |

**Table 9B.** Continued.

| Station Name | Structure Type | STA Site |
|---|---|---|
| S370A_C | Culvert | Yes |
| S370B_C | Culvert | Yes |
| S370C_C | Culvert | Yes |
| S371B_C | Culvert | Yes |
| S372C_C | Culvert | Yes |
| S373A_C | Culvert | Yes |
| S373B_C | Culvert | Yes |
| S374B_C | Culvert | Yes |
| G250S_P | Pump | Yes |
| G372_P | Pump | Yes |
| G600I_P | Pump | Yes |
| S319_P | Pump | Yes |
| S361_P | Pump | Yes |
| S362_P | Pump | Yes |

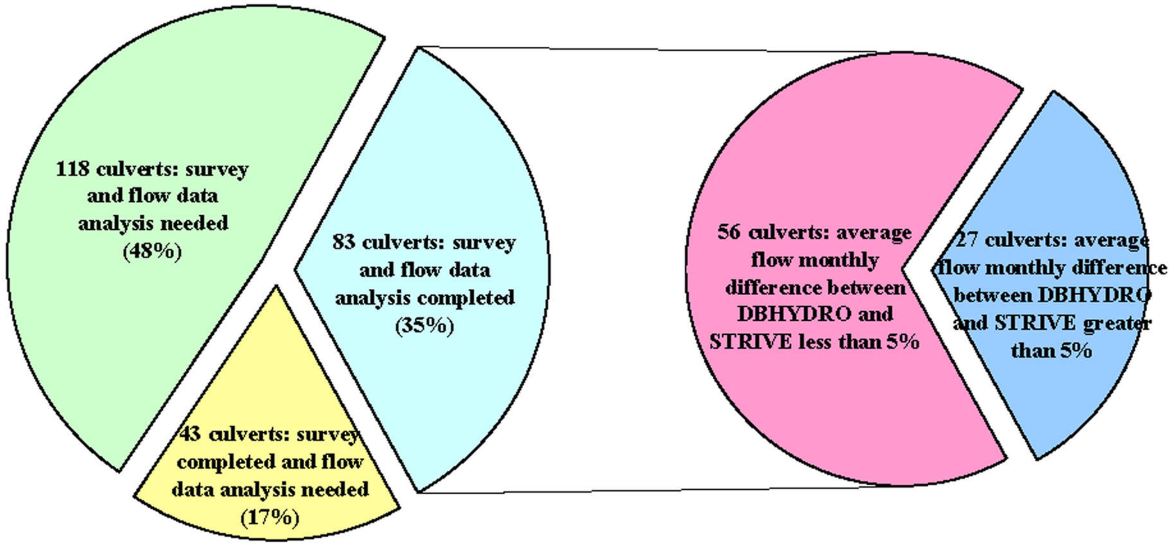


**Figure 5:** Status of survey and flow data analysis for culverts, as of March 2005.

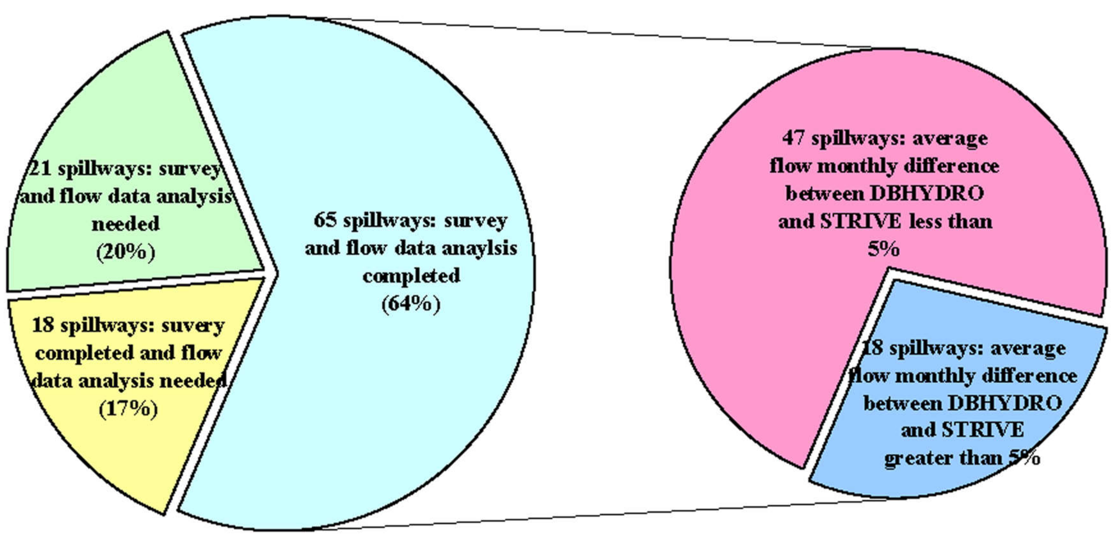


**Figure 6**: Status of survey and flow data analysis for spillways, as of March 2005.

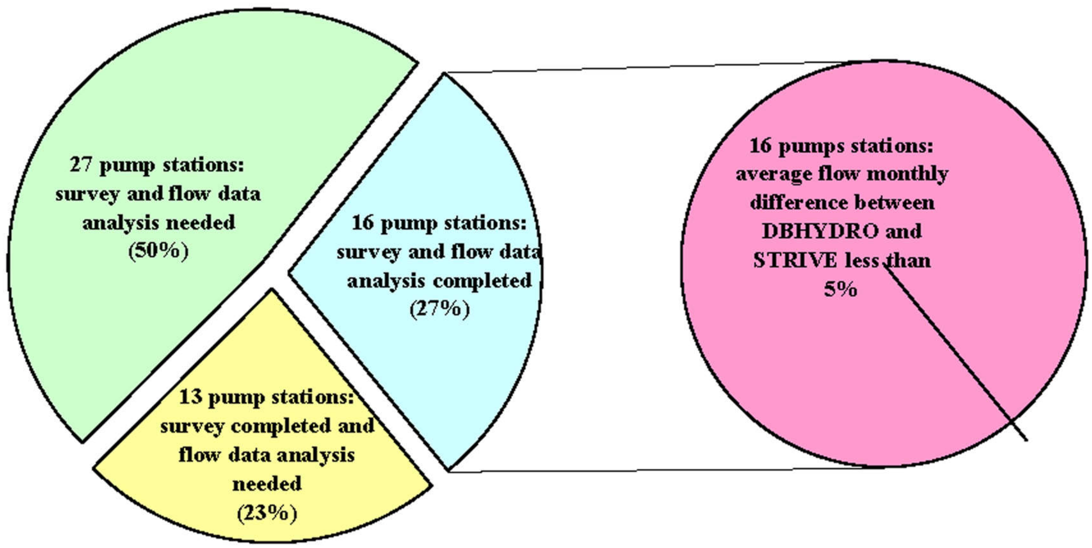


**Figure 7:** Status of survey and flow data analysis for pump stations, as of March 2005.

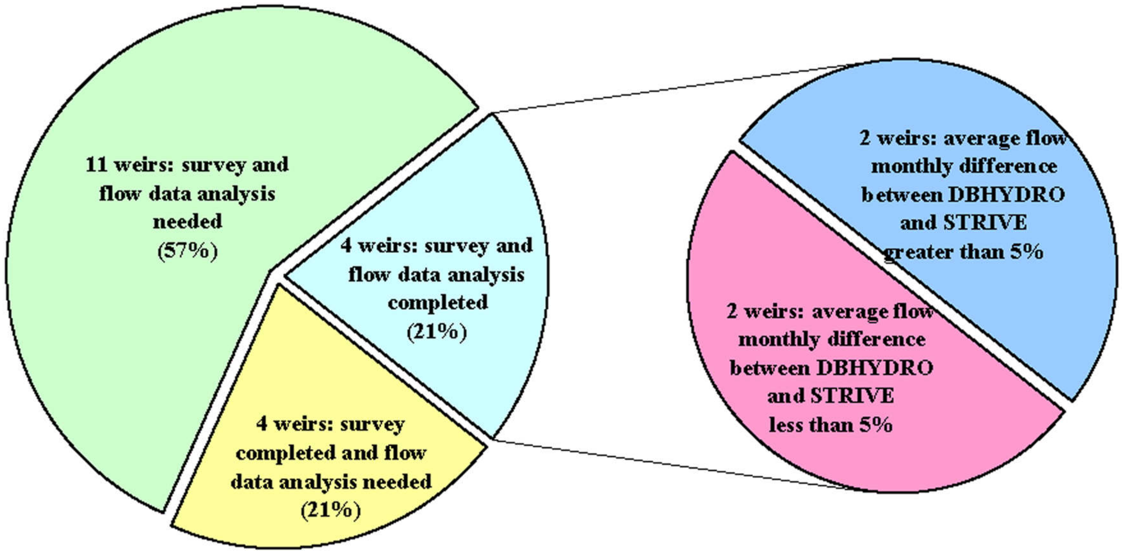


**Figure 8:** Status of survey and flow data analysis for weirs, as of March 2005.

# CONCLUSIONS

A total of 367 water control structures were field surveyed by the District during the last six years. Among these structures, 83 culverts, 65 spillways, 16 pump stations, and 4 weirs are registered in DBHYDRO database and flow data have been computed. Of these 168 structures, the structure data was compared with existing static data in DBHYDRO. New flow data was computed using new static data from the STRIVE project and were compared with historical flow data series from DBHYDRO. The work performed in this study evaluated the impacts of static data on historical flow data at each structure. Flow data for 168 structures was computed and compared. Field surveying for 78 structures was completed but flow data analysis is needed for these structures. Currently, 177 structures will need to be surveyed. Thirty-five of these structures have stream gauging data.

Average monthly differences in new and existing flow data were less than ±5 percent for 121 structures and the differences were greater than ±5 percent for 47 structures.

The structure static data in DBHYDRO will be revised, as appropriate, when the flow differences are greater than ±5 percent different, then data change procedures (Akpoji et al., 2003) will be used prior to revising the historical flow data series in DBHYDRO.

The STRIVE project is a critical effort in improving flow data that will benefit the District's various water resources projects. A significant effort is required to complete and continuously update the water control structures information and, therefore, several District staff has been dedicated to support this project.

# RECOMMENDATIONS

The following six recommendations are provided as a result of this study.

1. The STRIVE project should continue until all of the water control structures are field surveyed. This project has been worthwhile and resources expended for this purpose have been useful.

2. Upon completion of the STRIVE project, a new project should be initiated where only primary and secondary benchmarks of each water control structure are field surveyed every five years on cyclic basis. If benchmark elevations are changed beyond the specific limits (e.g., ±0.02 ft), then the entire water control structure should be surveyed during the benchmark surveys.

3. Distribution of the flow errors should be investigated. Specifically, the errors due to static information; errors due to dynamic information and errors due to rating equations should be determined.

4. Change in the static information of the pump structures did not produce any noticeable flow differences. Therefore, it is not necessary to perform flow data analyses for pump structures based on the STRIVE data unless significant differences are observed between physical parameters in the field and those in DBHYDRO.

5. For 27 culverts, 18 spillways and 2 weirs, where average monthly flow differences were greater than ±5 percent, present flow rating equations should be reexamined and revised where necessary.

6. For four culverts, three spillways and one pump station, where average monthly flow differences were less than ±5 percent and percent records that were greater than 20 percent, should be further analyzed.

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