December 2003
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EPA/600/R-04/034

Environmental Technology Verification Report

Wet Weather Flow Monitoring Equipment

ADS Environmental Model 4000 Open Channel Flow Monitor

Part I – Laboratory Test Results

Prepared by

NSF International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**AREA/VELOCITY FLOW MONITORS**	
APPLICATION:	**FLOW METERING IN SMALL- AND MEDIUM (10- to 42-inch) SEWERS**	
TECHNOLOGY NAME:	**ADS ENVIRONMENTAL SERVICES MODEL 4000 OPEN CHANNEL FLOW METER**	
TEST LOCATION:	**QUEBEC CITY, QUEBEC, CANADA, AND LOGAN, UTAH**	
COMPANY:	**ADS ENVIRONMENTAL SERVICES**	
ADDRESS:	**5030 BRADFORD DRIVE BUILDING 1, SUITE 210 HUNTSVILLE, AL 35805**	PHONE: **(800) 633-7246** FAX: **(256) 430-6633**
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NSF International (NSF) manages the Water Quality Protection Center (WQPC) under the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program. NSF evaluated the performance of the Model 4000 Open Channel Flow Meter manufactured by ADS Environmental Services. Utah Water Research Laboratory (UWRL) in Logan, Utah, and BPR of Quebec City, Canada, both NSF-qualified testing organizations, performed the laboratory and field verification testing, respectively.

EPA created the ETV Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated, and that the results are defensible.

TECHNOLOGY DESCRIPTION

The following technology description is provided by the vendor and does not represent verified information.

Area/velocity flow meters are commonly used in wastewater collection, storm sewer, and combined sewer systems. The ADS 4000 flow meter utilizes a quad-redundant ultrasonic sensor that measures the time required for an ultrasonic pulse to travel from the sensor face to the surface of the water and back to the sensor. The meter converts the travel time to distance by calculating the speed of sound through air and adjusting for temperature, which is measured by two sensors inside the ultrasonic sensor head. The depth of the flow is then calculated using the pipe diameter and the range measured by the ultrasonic sensor. A pressure-depth sensor is also installed at the bottom of the pipe to measure surcharge levels and to provide a redundant depth reading when used with the ultrasonic level sensor. Doppler velocity measurements are made by transmitting an ultrasonic signal upstream using a submerged velocity sensor and measuring the frequency shift in the sound waves reflected by the moving particles in the water. The depth and velocity sensor readings are stored in the flow meter's memory until the data can be downloaded to a computer through either a voice-grade telephone line or a cellular network. The computer software calculates flow rates using the depth and velocity readings.

The ADS 4000 flow meter system includes the flow meter unit, sensors, and installation hardware. The flow meter unit is housed in a waterproof, marine-grade aluminum housing. The submersible pressure sensor, ultrasonic level sensor, and velocity sensor are attached to a circular stainless steel band installed around the inner circumference of the sewer pipe. Waterproof cables with sealed connectors convey power and signals between the flow meter unit and the sensors. The system is battery-powered, and can power the unit for about one year at a standard 15-minute measurement interval. According to vendor claims, after the unit is installed, minimal operation and maintenance (O&M) or unit calibration is required; the most common O&M procedure is cleaning the sensors.

VERIFICATION TESTING DESCRIPTION

Laboratory Test Site

The laboratory testing was completed at the Utah Water Research Laboratory (UWRL), at Utah State University in Logan, Utah. The flow meter was installed in three nominal pipe sizes: 10-inch, 20-inch, and 42-inch. The straight lengths were sized so they were at least 40 times the pipe diameter for the 10- and 20-inch pipes and at least 22 times for the 42-inch pipes. Pipe slopes were adjustable to allow the flow meter to be evaluated under different slope conditions. Sluice gates at both ends of the pipes were used to regulate appropriate flow, head, and obstruction during testing. Reference devices were directly traceable to the National Institute of Standards and Technology (NIST), and were regularly calibrated. Uncertainty for the reference devices was less than 0.25 percent.

Field Test Site

Field verification testing was conducted in a section of the Quebec Urban Community's (QUC) sewer network, located in the City of Sainte-Foy, Quebec, Canada. The ADS flow meter and reference meters were installed in a 41.7-inch diameter interceptor pipe, near the downstream of a straight run of pipe that had an average slope of 0.169 percent. The reference devices, which consisted of a bubbler for a reference level measurement, a reference flow monitor, and an Accusonic 4-path flow monitor, were installed downstream of the ADS 4000 flow meter. Upstream and downstream sluice gates were used to create the required flow conditions.

Validation of the reference flow monitor and bubbler were performed by lithium tracer dye tests. Flow rates under the upstream and downstream gates were also calculated using standard hydraulic equations for a redundant check of flow data.

Methods and Procedures

Laboratory evaluation of the flow meters consisted of collecting depth, velocity, and flow data from the ADS meter and comparing it to the depth, velocity, and flow data from the reference devices. These tests were performed under normal operating conditions of uniform flow, backwater flow, full pipe (manhole surcharged), and simulated silt. Water transmission through the pipes, as a ratio of flow depth versus the pipe diameter (d/D), ranged from 10 to 250 percent (surcharged conditions). Tests were also performed under the abnormal operating conditions of reverse flow and grease accumulation.

Field evaluation of the ADS flow meter at the Quebec site consisted of a general evaluation of the flow meter (Test A) and the performance of the meter under varying flow conditions. Testing consisted of collecting depth, velocity, and flow data at regular time intervals and comparing the data to the corresponding depth, velocity, and flow data from the reference devices. Four test scenarios were used:

1. Test B—accuracy under dry weather flow (approximately 1.71 million gallons per day [MGD]), with back-flow conditions;
2. Test C—accuracy under wet weather flow (1.71–29.7 MGD), without back-flow conditions;
3. Test D—accuracy under wet weather flow (1.71–29.7 MGD), with back flow-conditions; and,
4. Test E—accuracy under short-term (26-day) continuous operation, with various flow rates.

Three conditions were identified during testing that created an unintended challenge to the ADS flow meter:

1. The water used in the testing at UWRL did not contain the particulate concentrations of normal sewage, so small quantities of coffee creamer were added to the water on some test runs. The operating principle utilized by the ADS flow meter requires particles in the water to serve as reflectors for sound waves. The vendor maintained that the coffee creamer additive provided a level of reflectivity, but the particulate concentration in the test water did not approach that of sewage and could be a source of measurement error.

2. During each field test, a portion of the ADS flow meter data collected at one-minute intervals was not recorded. ADS personnel indicated that this happened because the flow meter was configured for maximum error checking and sensor refiring. They further indicate that the ADS 4000 flow meter can be reconfigured to collect data at one-minute intervals by reducing the level of real-time error checking.

3. The field testing results include data in which it appears that standing waves and troughs were present beneath the ADS 4000 flow meter's ultrasonic depth sensor. During portions of the testing, the depth sensor was likely affected by standing waves and troughs up to $\pm$5 inches. The ADS flow meter measures depth with a downward-looking, narrow-beam ultrasonic sensor mounted on the top of the pipe, so depth measurements would be susceptible to influence by waves. Based on a review of the field data, it appears that waves were most prevalent at higher depths and flow rates.

No editing was allowed on the metered data during field or laboratory testing. In actual applications, the flow monitoring service provider may implement post-monitoring quality control measures to attempt to improve the accuracy of final data. According to ADS, the company typically bundles flow meter sales with post-monitoring quality control and reporting services.

VERIFICATION OF PERFORMANCE

System Operation

The testing organizations found the equipment durable and easy to use, and that it required minimal maintenance. The flow meter operation and data retrieval software programs were easy to learn. The ultrasonic sensors and stainless steel band did not promote accumulation of debris during testing.

Laboratory Testing Results

The mean deviation and the 95-percent confidence intervals under normal operating conditions (i.e., all test conditions except grease tests and reverse flow) are presented in Table 1. The width of the 95-percent confidence interval is a function of the variation in instrument deviation and of the number of test runs in each reported category. Categories with a fewer number of runs show wider confidence intervals. The calculations exclude "abnormal condition" tests, where grease was applied to the sensors or where reverse-flow conditions were created. The mean deviation for the abnormal operating conditions was 1.3 percent for the 0.5-mm grease tests, -69.5 percent for the 2.0-mm grease tests, and –62.4 percent for the reverse-flow tests.

Table 1. Deviation and 95-Percent Confidence Interval by Test Configuration for Lab Testing

Pipe size (inches)	Deviation (percent)	95-percent confidence interval (percent)
10	4.7	-6.5 – 15.8
20	-0.7	-7.9 – 6.6
42	-0.9	-10.8 – 9.0
Pipe slope (percent)		
0.1	4.7	-4.2 – 13.5
0.2	-0.9	-10.8 – 9.0
0.5	-0.8	-10.9 – 9.4
1.25	2.3	-10.8 – 15.4
2.0	0.2	-30.1 – 30.4
Percent full (d/D, percent)		
10	-0.1	-22.2 – 20.3
30	1.1	-13.5 – 15.8
50	5.4	-1.6 – 12.5
80	1.9	-7.4 – 11.2
150	-4.6	-28.8 – 19.6
250	3.3	-6.7 – 13.2
Condition		
Free flow	2.7	-4.3 – 9.7
Backwater	0.2	-7.5 – 8.0
All conditions	**1.2**	**-4.0 – 6.5**

The overall accuracy of the ADS 4000 flow meter under normal operating conditions (i.e., all test conditions except grease tests and reverse flow) is shown in Figure 1. The meter deviation is segregated into two components—bias and precision. Overall bias was 1.6 percent, as calculated by the slope of the best-fit line. Precision, as calculated with the correlation coefficient (r^2), was 0.74 percent.

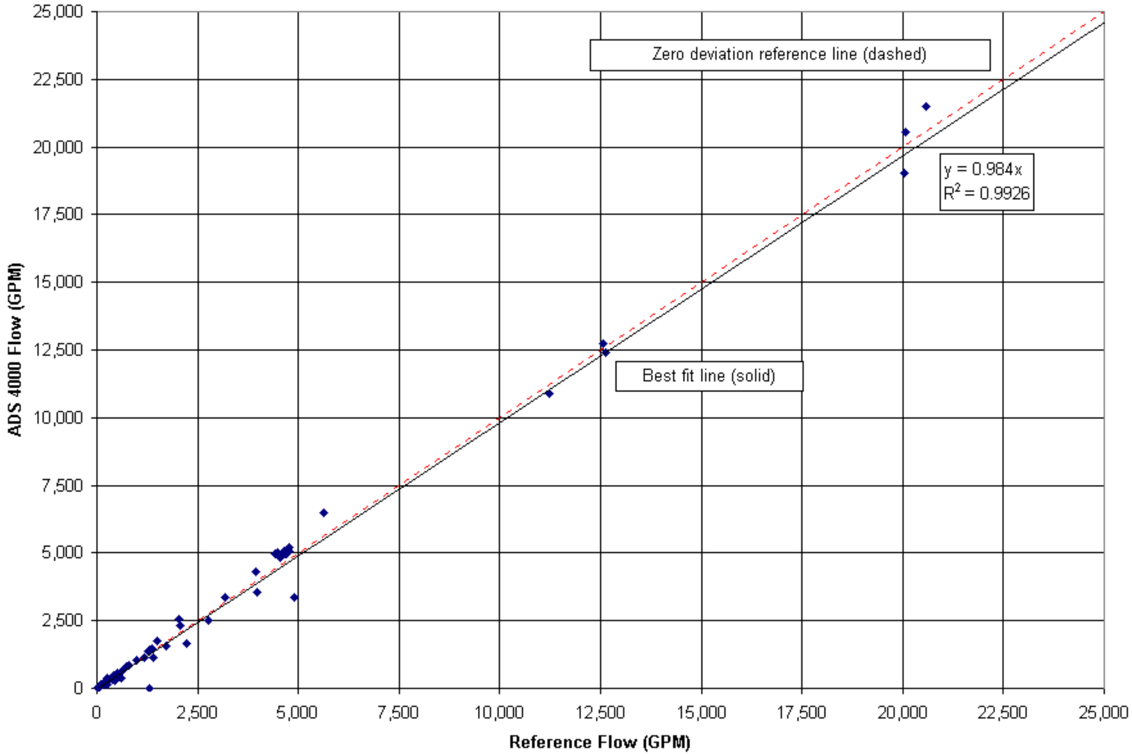

Figure 1. Laboratory-metered flow rate versus reference.

Field Testing Results

Table 2 summarizes the field testing results in two categories: mean deviation and trimmed mean deviation. The mean deviation is the arithmetic mean of all of the one-minute–interval data. The trimmed mean deviation is calculated by eliminating values greater than ±99 percent, making it less susceptible to skewing from large outliers, such as those produced when the ADS flow meter recorded zero velocity.

Table 2. Deviation from Reference Flow: Tests B, C, and D.

Flow regime	Mean deviation (percent)	Trimmed mean deviation (percent)
Test B	-14.5	-0.9
Test C	14.0	14.5
Test D	-0.8	8.3
Test B-D combined	**-0.4**	**3.8**
Simulated low flow	0.5	9.5
Simulated wet flow	-1.3	-1.0
Combined flows	**-0.4**	**3.8**

Analysis of the data collected during Test B (low flow) revealed that in nearly one-fourth of the samples the deviation was –100 percent. This occurred when the ADS 4000 flow meter recorded zero velocity and calculated the flow to be zero. This occurred most frequently when the pipe experienced back-flow conditions. The data collected during Tests C and D shows a significantly lower occurrence of data with deviations exceeding ±99 percent.

Test E (not included in Table 2) evaluated the performance of the flow meter over an extended (26-day) time period. Generally, the data collected during Test E closely correlated with the reference flow monitor data. Spikes were noted in water level measurements collected toward the end of the test, which may have been the result of accumulated condensation on the ultrasonic depth probe. No debris accumulation was observed on the equipment, and, aside from a thin film of grease on the probes, the equipment was in good condition and did not require maintenance.

QUALITY ASSURANCE/QUALITY CONTROL

A complete description of the quality assurance/quality control procedures and findings are included in the verification reports. Calibration records were maintained by the testing organizations and validation of the reference flow devices fell within control limits. NSF completed a data quality audit of at least 10 percent of the test data to ensure that the reported data represented the data generated during testing. Audits of the field and laboratory testing were conducted by NSF with no significant issues noted.

Original Signed by
Lee A. Mulkey *March 31, 2004*

Lee A. Mulkey Date
Acting Director
National Risk Management Laboratory
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Original Signed by
Gordon Bellen *April 26, 2004*

Gordon Bellen Date
Vice President
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NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology, and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report is not an NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents
Copies of the *Draft 4.0 – Generic Verification Protocol, Flow Monitors for Wet Weather Flows Applications in Small- and Medium-Sized Sewers, September, 2000,* the verification statement, and the verification report (NSF Report #03/13/WQPC-WWF) are available from:

ETV Water Quality Protection Center Program Manager (order hard copy)
NSF International
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Ann Arbor, Michigan 48113-0140
NSF web site: http://www.nsf.org/etv (electronic copy)
EPA web site: http://www.epa.gov/etv (electronic copy)

(NOTE: Appendices are not included in the verification report. Appendices are available upon request from NSF.)

Environmental Technology Verification Report

WET WEATHER FLOW MONITORING EQUIPMENT VERIFICATION

ADS ENVIRONMENTAL MODEL 4000
OPEN CHANNEL FLOW MONITOR

PART 1: UTAH WATER RESEARCH LABORATORY TEST SITE

Prepared for:

NSF International
Ann Arbor, Michigan

Prepared by:

UTAH WATER RESEARCH LABORATORY
Logan, Utah

December 2003

Under a cooperative agreement with the U.S. Environmental Protection Agency

Raymond Frederick, Project Officer
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Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under a cooperative agreement. This verification effort was supported by the Water Quality Protection Center operating under the Environmental Technology Verification (ETV) Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

The following is the final report on an Environmental Technology Verification (ETV) test performed for the NSF International (NSF) and EPA by the Utah Water Research Laboratory (UWRL) and BPR, in cooperation with ADS Environmental. This final report is divided into two parts. This part includes the introduction and outlines the summary of the laboratory testing procedures. Part II: Quebec Urban Community Test Site outlines the summary of the field testing procedures. Both parts are available on the NSF and EPA websites.

Contents

Tables

Figures

Acronyms and Abbreviations

ADS	ADS Environmental Services, a division of ADS Corporation
BPR	BPR, Quebec, Canada
cfs	Cubic feet per second
ENS	Event Notification System
EPA	United States Environmental Protection Agency
ETV	Environmental Testing Verification
ft	Foot or feet
FTO	Field testing organization
gpm	Gallons per minute
in.	Inch or inches
lb	Pound
LTO	Laboratory testing organization
mg/L	Milligrams per liter
min	Minimum
NIST	National Institute of Standards and Technology
NSF	NSF International (formerly National Sanitation Foundation)
NTU	Nephelometric turbidity units
QA	Quality assurance
QUC	Quebec Urban Community
SAG	Stakeholders Advisory Group
SCADA	Supervisory control and data acquisition
UWRL	Utah Water Research Laboratory
VTP	Verification test plan
WWF	Wet weather flow

Acknowledgments

The Laboratory Testing Organization, Utah Water Research Laboratory, and the Field Testing Organization, BPR, Quebec, Canada, were responsible for all elements in the testing sequence, including test set-up, calibration and verification of instruments, data collection and analysis, data management, data interpretation, and the preparation of this report.

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The Utah Water Research Laboratory wishes to thank the UWRL shop for the many hours spent preparing the piping for these tests. Also, special thanks to Utah State University Engineering students Randy Geldmacher, Tyler Smith, John Nunley, and Garrett McMullen for their assistance in establishing proper test conditions and collecting test data. It is also necessary to thank ADS personnel for their support throughout the test program. ADS support was provided by George Kurz, Pat Stevens, Keith Waites, Christy Kennamer, Heather Hackett, Jeffrey White, Erica Blanken, Mark MacPherson, and Gillian Woodward.

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV achieves this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory testing (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) operates the Wet Weather Flow (WWF) Technologies Area in cooperation with the EPA under the Water Quality Protection Center. The WQPC evaluated the performance of the ADS Model 4000 open channel flow monitor, which is an area/velocity flow meter used to measure flows in municipal sewers. The performance claim evaluated during laboratory testing of the ADS Model 4000 was that the instrument is capable of measuring depths and velocities in a wide range of pipe sizes and flow conditions. This document provides the laboratory verification test results for the ADS Model 4000 open channel flow monitor.

1.2 Testing Participants and Responsibilities

The ETV testing of the ADS Model 4000 open channel flow monitor was a cooperative effort of the following participants:

- U.S. Environmental Protection Agency
- NSF International
- Utah Water Research Laboratory
- BPR
- ADS Environmental

The following is a brief description of the ETV participants and their roles and responsibilities.

1.2.1 U.S. Environmental Protection Agency

The EPA Office of Research and Development, through the Urban Watershed Branch, Water Supply and Water Resources Division, National Risk Management Research Laboratory (NRMRL), provides administrative, technical, and quality assurance guidance and oversight on all ETV Water Quality Protection Center activities.

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1.2.2 NSF International

NSF is a not-for-profit testing and certification organization dedicated to public health, safety, and protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in the development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF Name, Logo and/or Mark meet the organization's standards.

NSF had several different roles in completing this verification. NSF reviewed the verification of the verification test plan (VTP) and provided technical oversight of the verification testing, including auditing of the laboratory's analytical, data gathering, and data recording procedures. NSF also provided review of this verification report.

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1.2.3 Laboratory Testing Organization

The Utah Water Research Laboratory (UWRL), a Utah State University hydraulic research facility, is an NSF-qualified testing organization (TO) for the WQPC and conducted the verification testing of the ADS 4000 flowmeter. UWRL provided all needed logistical support, established a communications network, and scheduled and coordinated the activities of all participants. It was responsible for ensuring that the testing location and feed water conditions could meet the stated objectives of the verification testing. UWRL prepared the VTP; oversaw the pilot testing; managed, evaluated, interpreted and reported on the data generated by the testing; and evaluated and reported on the performance of the technology.

UWRL employees manufactured and prepared the test piping, set test conditions, and measured and recorded data during the testing. The UWRL's Project Manager provided testing oversight.

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1.2.4 Field Testing Organization

BPR is an NSF-qualified TO for the WQPC and was responsible for conducting the field verification testing of the ADS 4000 flowmeter. The testing was conducted on a section of the Quebec Urban Community's (QUC) western sewer network located in the City of Sainte-Foy, along the east side of Boulevard Chaundière, approximately between Bombardier and Mendel Streets.

BPR provided all needed logistical support, established a communications network, and scheduled and coordinated the activities of all participants. It was responsible for ensuring that the testing location and feed water conditions could meet the stated objectives of the verification testing. It prepared the VTP, oversaw the pilot testing; managed, evaluated, interpreted, and reported on the data generated by the testing; and evaluated and reported on the performance of the technology.

BPR employees prepared the test site, set test conditions, and measured and recorded data during the testing. BPR's Project Manager provided oversight of the daily tests.

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1.2.5 Vendor

The flow monitoring equipment is manufactured by ADS Corporation, a manufacturer of area/velocity flow monitoring equipment. ADS was responsible for supplying a field-ready open channel flow meter equipped with all necessary components, including an installation and operation manual. The manufacturer was also responsible for providing technical support personnel. This individual was responsible for installing and precalibrating the flow monitoring equipment in the simulated sewer for each test series, and was available during all tests to provide technical assistance as needed.

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1.3 Laboratory Verification Testing Site

The Utah Water Research Laboratory, constructed in 1965, is one of the largest water research laboratories of its kind in the country. The laboratory, which occupies more than 50,000 square feet of floor space, contains a variety of flumes, channels, pumps, pipelines, equipment, and instrumentation for conducting hydraulic research, model studies, hydraulic valve testing, and flow meter calibrations. It is capable of performing an array of hydraulic tests and research programs. A network of steel piping (18-, 24-, 36-, and 48-inch diameter), located under the floor of the lab, provides maximum flexibility in constructing test lines from 1/2-inch to 60-inches. Under-the-floor channels conduct water from the experiments back to the river, to recirculating pumps, or to the precise flow measurement facilities.

The primary water supply for the laboratory is an 85-acre-foot reservoir approximately 500 feet from the facility. The water supply, which is conveyed to the laboratory through a 48-inch pipe, provides a constant 25 feet of head to the main level of the laboratory and 35 feet of head to the lower level at shutoff. Flow can also be supplied from either high-pressure pumps or a constant level tank within the laboratory.

For direct National Institute of Standards (NIST) traceability, flow rates are measured using the laboratory's weigh and volumetric tanks. These tanks are calibrated regularly and are NIST-traceable by weight. The UWRL primary flow measurement system consists of one 1,000 lb weigh tank, two 30,000 lb weigh tanks, and a 222,144 lb (3,560 ft^3) volumetric tank. Flow rates up to 40 cubic feet per second (cfs) can be accurately measured with the primary flow measurement system.

A number of venturi meters—6-, 12-, 20-, 24-, and 48-inch—are installed in various test lines throughout the laboratory. These master meters are calibrated in place using the UWRL primary flow measurement system. As a secondary standard with NIST-traceability, these meters allow accurate flow measurements to be made for flow rates up to approximately 200 cfs.

Chapter 2
ADS Equipment Description and Operating Processes

The information contained in this chapter is provided by the vendor and does not represent verified information. The information is intended to provide the reader with a description of the ADS 4000 flow monitor and to explain how the technology operates. The verified performance characteristics of the ADS 4000 are described in subsequent chapters.

2.1 Equipment Description

The instrument verified was an ADS 4000 open channel flow monitor manufactured by ADS. The ADS 4000 flow monitor is specially designed to meet the demands of measuring flow over long-term periods in open channel applications such as wastewater collection systems, storm sewer systems, and combined sewer systems. The battery-powered system acquires highly accurate depth and velocity data, and transmits the data through telemetry to a remote computer.

The ADS 4000 is used for many project applications, including:

- Infiltration/inflow analysis and reduction;
- Master plan studies;
- Interagency billing networks;
- Combined sewer overflow characterization;
- Storm sewer monitoring;
- Sewer capacity analysis; and
- Sewer system performance studies/trending.

Precise pipe dimensions (height and width) are measured during installation because they are critical to both depth and cross-sectional area. ADS depth sensors measure the distance from the down-looking sensor to the water surface (range) and depth of flow is obtained by subtracting the range from the diameter. This is an important step since the inside diameter of most sewer pipe is not equal to its nominal diameter. Velocity sensor confirmation is another critical-to-quality activity. While the ADS 4000 velocity sensor will perform in most sites using factory default settings, it can be adjusted by a trained technician to improve performance in unique hydraulic conditions.

The Model 4000 features:

- <u>Advanced Software Filtering</u>. Smart depth helps compensate for adverse monitoring conditions such as waves, foam, debris, etc.
- <u>Peak Velocity Sensor</u>. Readings from this sensor are used to calculate average flow velocity. Its miniature size and streamlined design minimize fouling and prevents flow disruption.
- <u>Pressure Depth Sensor</u>. This sensor is used to measure surcharge levels or to provide a redundant depth reading when used in conjunction with the ultrasonic level sensor.

- Water Quality Sampler Interface. A variety of industry standard water quality samplers are compatible and easily interfaced with the Model 4000. Sampling is initiated automatically on a fixed-time or flow proportional basis.
- Tipping Bucket Interface. Where installation criteria allow, the flow monitor can be interfaced to a tipping bucket to record rainfall amounts.
- Accurate Flow Measurement. This technology has been verified as highly accurate in both laboratory and in-field tests; measures flow under open channel, free flow conditions, and nonfree flow conditions including surcharge and backwater.
- Monitor-Level Intelligence (MLI). The Model 4000 contains ADS's MLI algorithms. With MLI, the monitor "learns" the hydraulic profile of its environment. MLI continuously references this learned profile to detect flow changes immediately. When changes are detected, MLI optimizes sensor performance and readings. This improves accuracy and allows the monitor to work in a wider range of hydraulic conditions.
- Profile™ Software Compatible . Profile is a Windows®-based package specially designed for flow data management, analysis, trending, and reporting. Profile combines the interface operations, navigation tools, and general functionality common to all Windows®-based software, with the in-depth technical capabilities and collection system-specific applications required to fully maximize flow data usage.
- FieldScan™ Software Interface. The interface communicates with monitoring units on-site for technical troubleshooting, data review, and data collection.
- Low Cost Telemetry. Standard voice-grade telephone telemetry allows remote communications and diagnostics, resulting in a significant reduction in field labor.
- Wireless-Ready. Available in a wireless-ready configuration, the Model 4000W communicates through either a cellular modem or Spread Spectrum Radio link. The wireless-ready version (4000W) can be ordered directly from the factory or a standard Model 4000 can be field retrofitted.
- Data Transmission Integrity. This is guaranteed through use of hand-shaking identification and proprietary communications protocol with CRC-16 error checking.
- Lightning Protection. Transient suppressors on the telephone line protect the unit against nominal lightning surges.
- Event Notification. An optional feature, this notifies operator that a preset condition, i.e., high depth, is detected.
- Data Storage. Unit has 1 megabyte of memory for data storage; storage duration dependent upon configuration.
- Ultra Lower Power Consumption. Batteries can last more than one year under most operating and environmental conditions.
- External Power. This is available with an external DC power input.
- Low Battery Warning. Each unit monitors battery voltages to warn the operator in advance of battery failure.
- Fully Water Resistant Housing. The housing reliably withstands harsh sewer environments, even under surcharge conditions.
- Manufacturing Quality Control. Each unit undergoes factory testing and certification by qualified technicians.
- Electronic Maintenance. Modular subassemblies allow for more efficient maintenance.

Figure 2-1 is a view of the ADS 4000 meter's canister. Figure 2-2 shows the stainless steel ring and sensing devices installed inside a pipe.

Figure 2-1. ADS Model 4000 Open Channel Flow Monitor.

The ADS meter installation is similar to nearly all depth velocity meters, but the ADS meter differs in that only its velocity sensor is mounted in the flow. The velocity sensor offers a cross-sectional area of around one-half square inch, and measures velocity in depths of less than one inch. Both the depth and velocity sensors are mounted on a stainless steel ring that is expanded into place with a hand crank and spreader bars. The meter is either attached to rungs in the manhole or to an attachment hook drilled into place on the manhole wall. The meter is activated by downloading BASIC code with monitor and sensor configuration. The monitor clock is synchronized with the central computer each time data is collected.

It is important that the actual pipe dimensions be measured for two reasons: (1) the correct diameter will be used to calculate cross-sectional area of the pipe; and (2) the depth of flow equals the actual diameter minus the range measured by the depth sensor. An incorrect diameter translates directly to an incorrect depth. The inside diameter of most sewer pipe is not equal to its nominal diameter. For example, a 15-inch PVC sewer line with SDR 35 wall thickness has a maximum manufactured diameter of 14.4 inches.

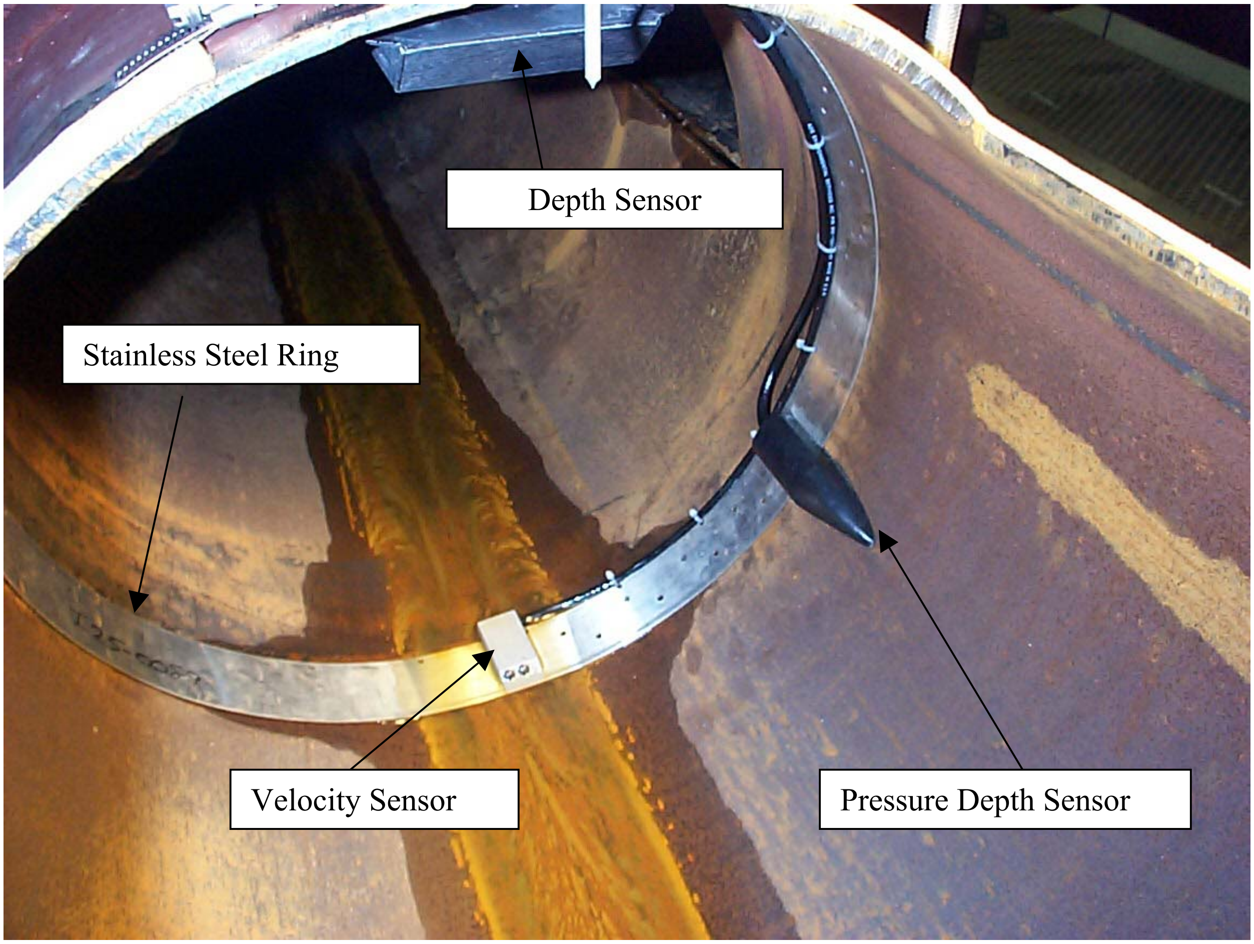


Figure 2-2. ADS flow monitoring sensors (laboratory 20-inch installation).

The monitor and software manuals offer approximately 600 pages of instruction, including graphics, on installing the meter, activating the meter, collecting data, and processing data.

ADS provides hardware as well as flow monitoring services throughout the United States. Technical support is provided by its headquarters office as well as by 16 regional and local offices. Most offices are staffed with data analysts and operations people who will readily assist with any hardware, software, or operational problem. Parts can be ordered through any office.

No special tools are required for installation. Most installations are accomplished with standard wrenches, screwdrivers, wire ties, and a drill and bits.

Once placed in service, continued calibrations are not required to obtain valid data, but periodic site visits are recommended to spot hydraulic changes. The ultrasonic sensor has zero drift, but it is recommended that the sites with silt be visited regularly to verify silt depth. Silt reduces the cross-sectional area of flow and creates inaccuracy in the continuity equation. Hydraulic changes can also affect the average-to-peak ratio, which should be confirmed periodically through velocity profiles.

The unit operates with little routine maintenance. The most common maintenance needed is cleaning the ultrasonic depth sensor should it become coated with grease during a surcharge event in a greasy sewer. In most sewers the ultrasonic sensors are not affected by surcharging, and they immediately begin reporting depth the moment surcharging subsides. The velocity sensor is not affected by grease, but can be impaired by heavy silt or debris covering the sensor. In such cases, the sensor can be rotated off the bottom of the sewer to avoid silt and debris. Ultrasonic depth sensor crystals that deteriorate with age can be diagnosed and taken out of service remotely. A visit to the site can be avoided by switching to an inactive sensor pair. There are 12 possible sensor pairs, and the meter will operate with only one pair in service.

2.2 Operating Process

2.2.1 Depth

Depth is measured by a quad-redundant ultrasonic sensor installed at the top of the pipe facing down toward the water surface. The meter measures the time of travel of an ultrasonic pulse from the sensor to the water and back to the sensor. The meter converts the time of travel to distance by calculating the speed of sound through air and adjusting for temperature, which is measured by two temperature sensors inside the ultrasonic sensor head.

Each of the four transducers can operate in either transmit or receive mode, allowing for 12 possible transmit–listen pairs, as illustrated in Figure 2-3. A crystal cannot transmit and listen for its own signal. The paired sensors essentially eliminate the dead zone inherent to a single ultrasonic crystal that transmits and then listens. The dead zone is usually less than one inch.

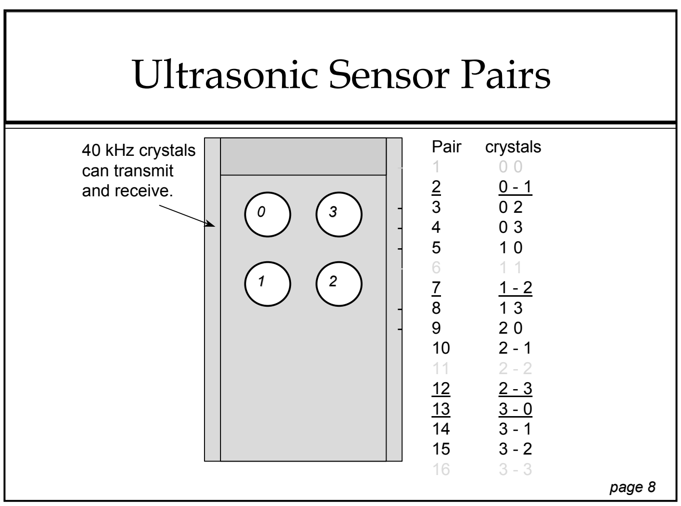


Figure 2-3. Ultrasonic sensor illustration.

Up to four of the 12 sensor pairs are in operation at any moment, and the operator can remotely diagnose the operating pairs for strength and quality of signal. The operator can remotely add and remove sensor pairs from operation. When activated for a reading, each pair in turn measures distance 32 successive times for a total of 128 readings. Errant readings from each sensor pair are discarded and four depth readings are recorded. The sensors are designed to have zero drift, and only extremely noisy or wavy sites affect performance.

2.2.2 Velocity

Doppler velocity measurements are made by transmitting an ultrasonic signal upstream and measuring particle velocity, similar to police radar. The sensor receives echoes from the particles and records the frequency shift (velocity) and strength of each echo. The ADS 4000 uses Peak Velocity Doppler, which is ADS's third generation velocity technology (V3). V3 technology takes advantage of the fact that the fastest particle in sewage remains constant from moment to moment, regardless of its size. V3 technology measures the velocity of the fastest particle (particle C in Figure 2-4) in sewage and converts it to average velocity. The ratio of average to peak velocity is around 0.9 in most sewers, and velocity profiles are used to determine the ratio in unusual flow.

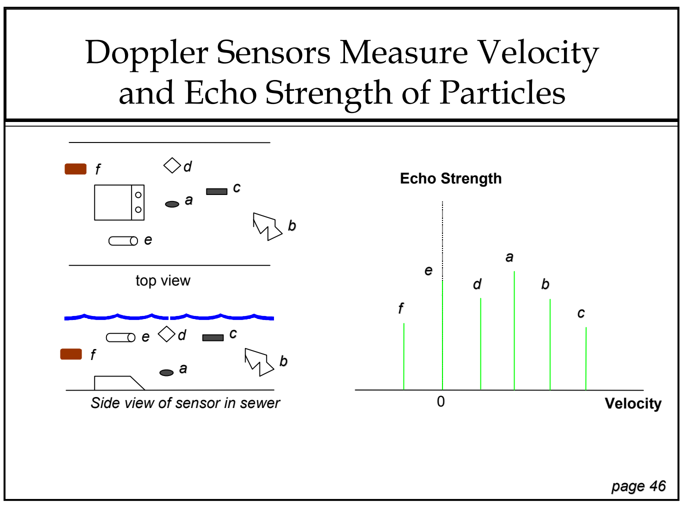


Figure 2-4. Doppler velocity sensor illustration.

Chapter 3
Laboratory Report

This chapter presents the procedures used in generating the laboratory performance data for the ADS 4000, along with the test data generated from the verification testing. This chapter addresses only the laboratory portion of the verification. Chapter 4, contained in Part II of the report, addresses the field testing portion of the verification testing.

3.1 Test Set-up, Test Equipment, and Procedures

3.1.1 Test Description

The laboratory flow meter verification was performed in three different nominal pipe sizes: 10-inch, 20-inch, and 42-inch. Figures 3-1 through 3-3 show the piping prepared for the tests in the three respective sizes. Although the schematic drawings are not to scale, the dimensions and the relative locations of flow meters, risers, valves, and manholes are accurate. Each set-up was constructed using steel pipe.

An opening was cut in the top of the pipe near where the vendor test sensors were installed. The opening provided access to the sensor location so that a precision point gauge could be used to accurately measure flow depths and to allow test participants to view the installation from above to observe flow conditions around the flow meter. The access opening had a watertight cover that was closed during pressurized (full-pipe) tests. Figure 3-4 shows the 20-inch pipe set-up with the access hole open and closed. The other pipe size set-ups were similarly constructed.

A manhole was also constructed in each test set-up near the location of the test flow meter. The size and location of the manhole was sufficient to provide access for the installation of the test flow meter, and to provide a suitable location for monitoring surcharge flow conditions. The manhole consisted of a cylindrical steel tank with a watertight bottom. Each manhole was constructed to the dimensions indicated in the figures. The top was removed from the section of pipe passing through the manhole (down to the spring-line). A sloping steel floor was installed in the bottom of the manhole so that all water drained to the pipe spring-line. Figure 3-5 is a photograph of the outside and the inside of the manhole in the 20-inch pipe set-up. The other pipe size set-ups were similarly constructed.

The test flow meter sensors were installed in the upstream pipe adjacent to the manhole. The precise location of the meter in the test pipe depended on ADS's specifications for the meter and its installation requirements. The crown of the pipe was removable near the installation location for access to the installed flow meter, but this access location was not used to install the flow meter. The access hole was covered and sealed for tests requiring surcharged flow conditions. All cables and wires connected to the sensor were directed into the test pipe through the manhole.

In the 10- and 20-inch test pipes, the length of straight pipe installed upstream of the manhole/flow meter test location was at least 40 times the pipe diameter. This length of straight pipe was necessary to provide near-uniform flow to the flow monitoring equipment during tests with no backwater effects. In the 42-inch test pipe, the length of straight pipe upstream of the manhole/flow meter test location was at least 22 times the pipe diameter. This shorter length was sufficient to provide near-uniform flow at the single pipe slope (0.2 percent).

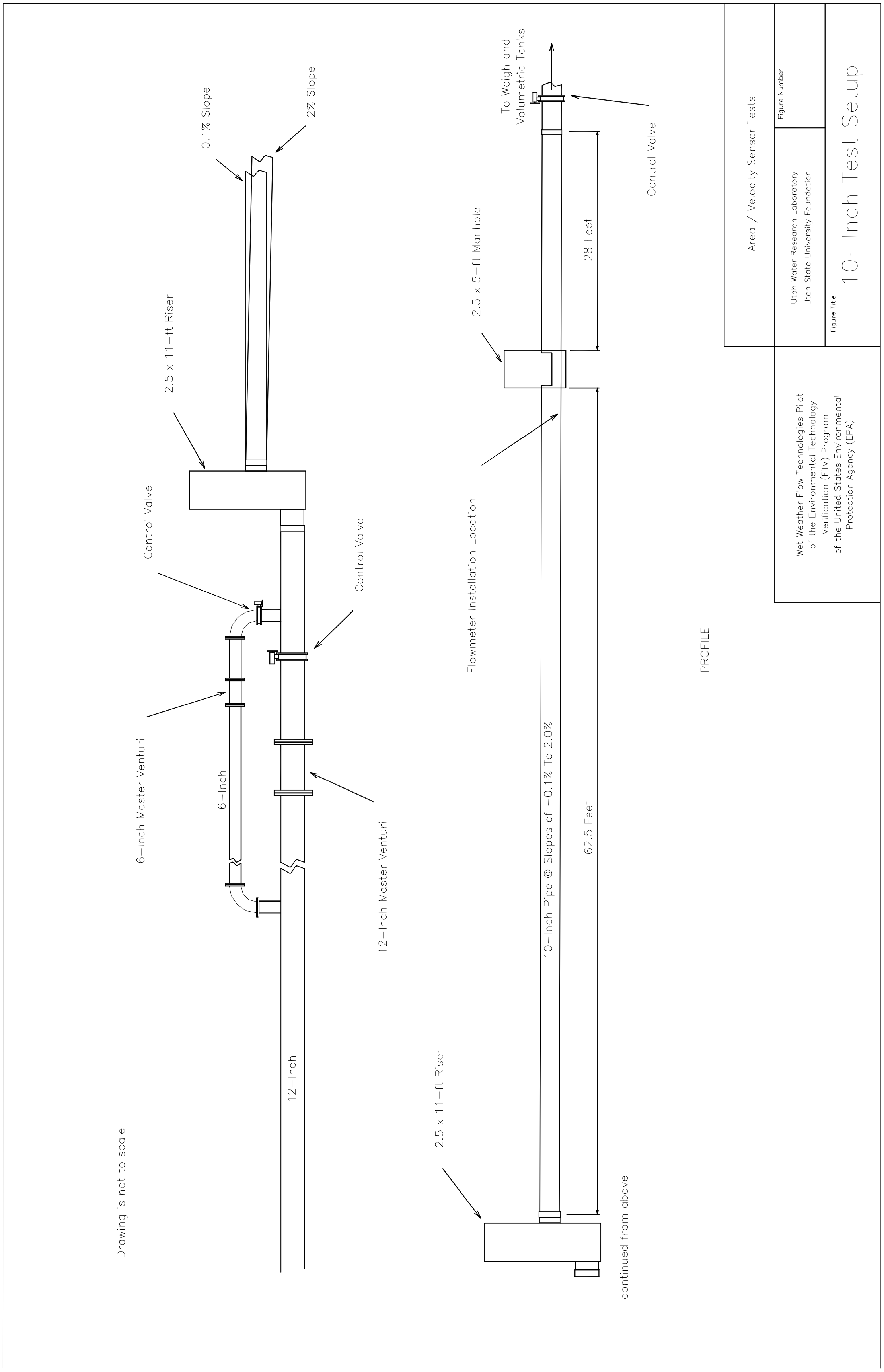


Figure 3-1. The 10-inch pipe test set-up

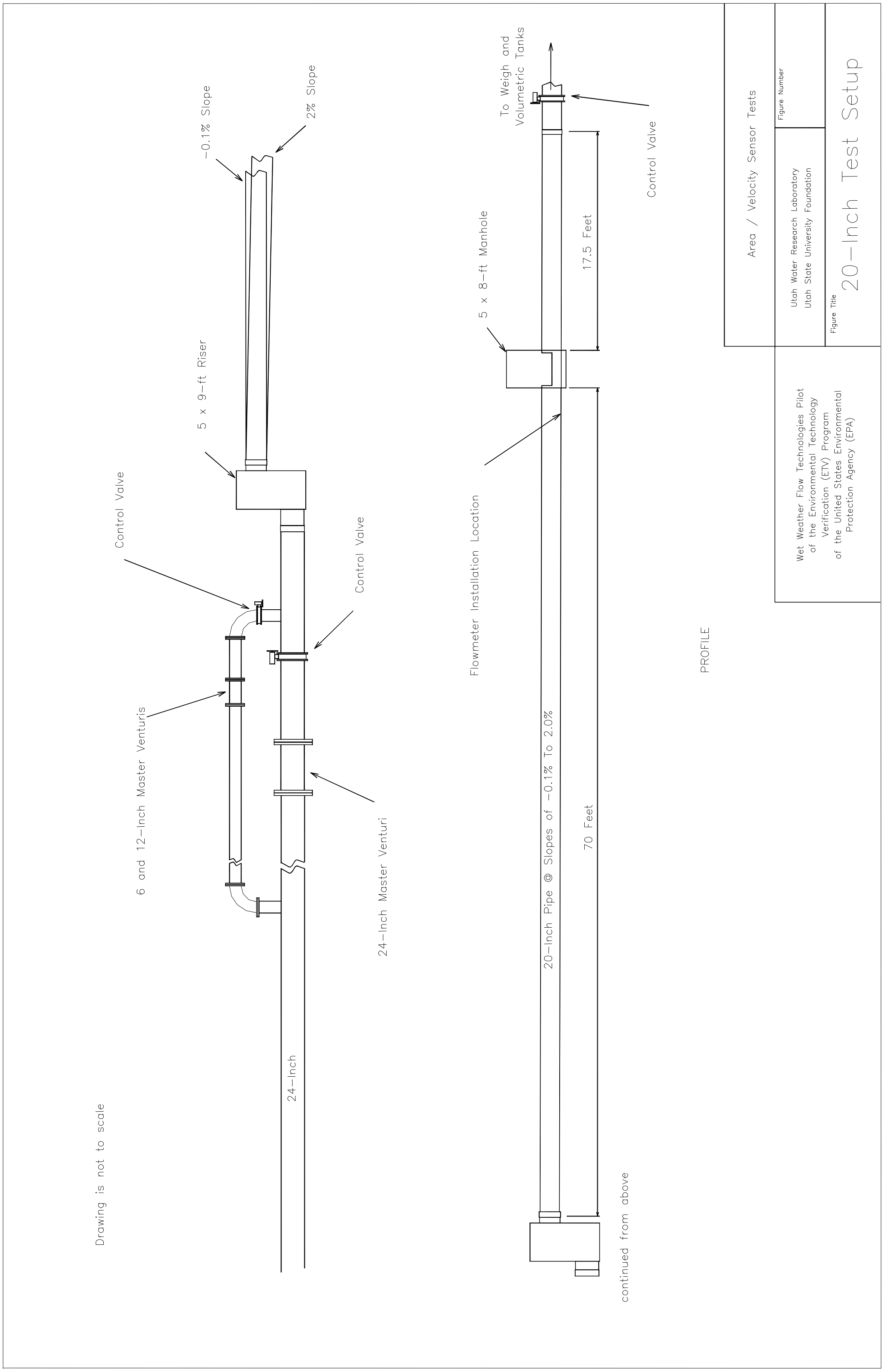


Figure 3-2. The 20-inch pipe test set-up.

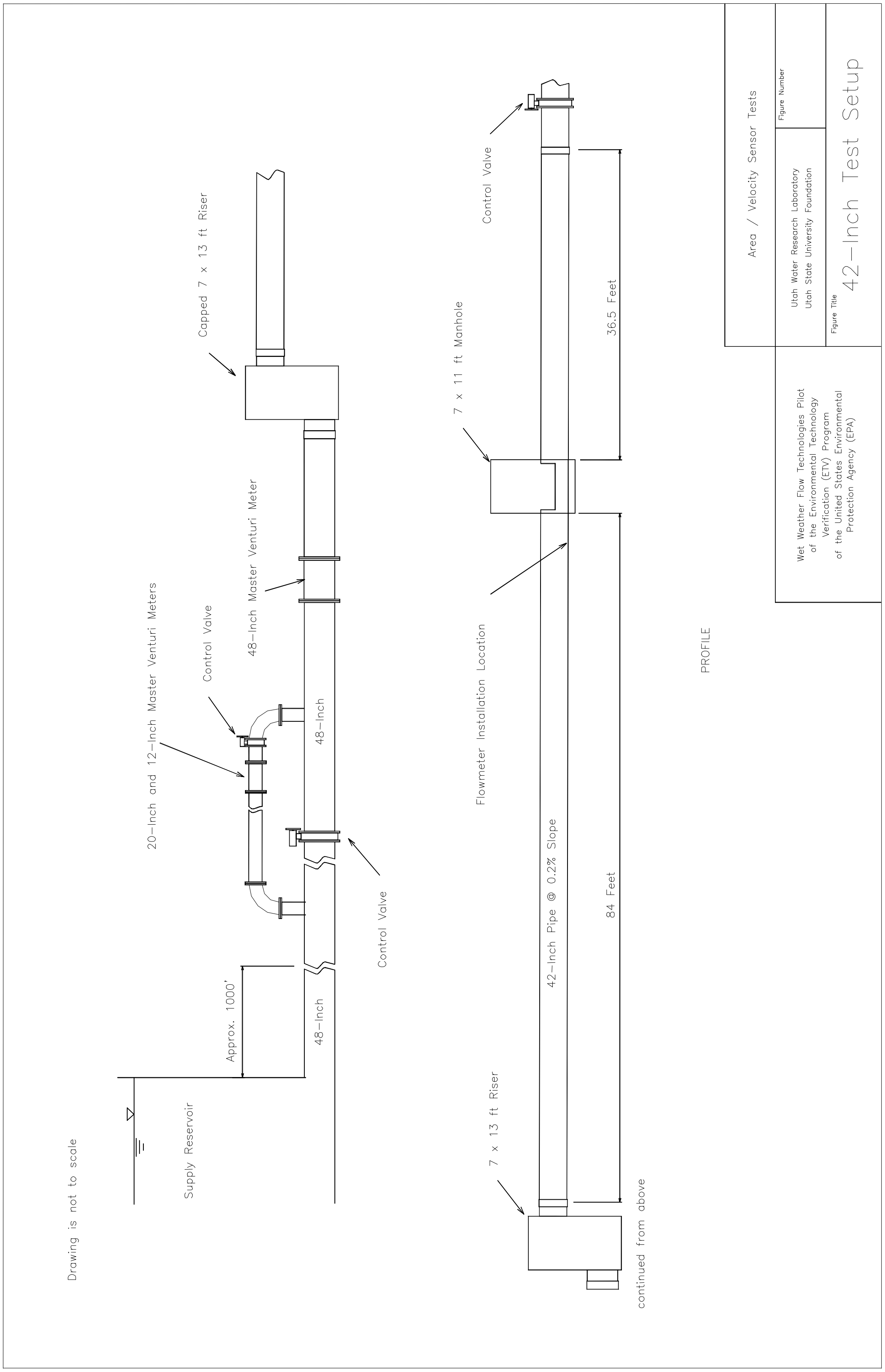
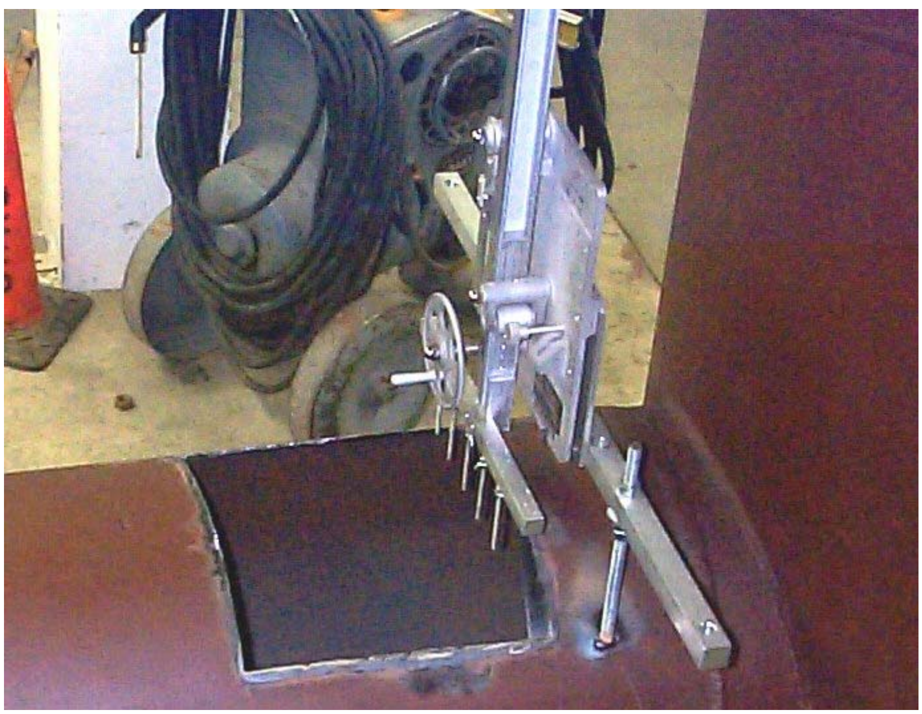


Figure 3-3. The 42-inch pipe test set-up.

(a) Closed pipe.



(b) Open pipe.

Figure 3-4. The access hole opening for testing.

(a) Outside view.

(b) Inside view

Figure 3-5. View of manhole for 20-inch pipe.

A minimum of 10 diameters of straight pipe was installed downstream of each manhole to simulate the flow conditions exiting the manhole. Figure 3-6 shows the 20-inch set-up. The other pipe size set-ups were similarly constructed.

Figure 3-6. The 20-inch simulated sewer (riser-pipe-manhole, right to left).

Each test line was laid at a constant slope along the full length of the pipe. The test set-up allowed for the adjustment of pipe slope in the 10- and 20-inch sizes. The supports for these two test lines were capable of supporting pipe from a slightly negative slope condition to a maximum slope of 2.0 percent. The 42-inch pipe set-up was set at a constant slope (0.2 percent) for all tests. The vertical pipe supports prevented the pipe from sagging under the weight of the water. The spacing between vertical pipe supports for the three steel pipe set-ups was no greater than ten pipe diameters. No horizontal supports were needed.

A control valve was placed both upstream and downstream of the model piping. The valves were used to control the rate of flow through the simulated sewer. The upstream valve was used to control the rate of flow entering the riser supplying the test line. The downstream valve was used to impose a downstream control to the test line, providing backwater during surcharge test conditions.

A vertical riser was installed upstream of each test pipe to help dissipate the energy of the incoming flow, to provide a smooth pour-over into the model pipe for open channel tests, and to provide a surcharge stand-pipe during full-pipe tests. The dimensions of each riser are shown in Figures 3-1 through 3-3.

The test pipe was connected to the vertical supply riser with a flexible coupling that allowed for the required adjustment of pipe slope. The point of connection was high enough on the riser to allow the test pipe to be set at a maximum slope of 2.0 percent along its entire length. (The coupling can be seen on the right side of the photograph in Figure 3-6. In the photograph, flow is from right to left). The elevation of the pipe at the coupling was always the same. The adjustable stands were raised or lowered to set the appropriate slopes for each test so that the entire test line rotated about the upstream coupling.

Water was supplied by a reservoir near the laboratory. This constant head source was capable of maintaining constant and steady water depths in the test pipe for the duration of each test run. A turbidity test was performed in the Environmental Quality Laboratory at UWRL and found to be at a level of 0.58 nephelometric turbidity units (NTU). One NTU is the limit for public drinking water supplies. The lower limit on the laboratory meter that made the measurement is approximately 0.1 NTUs. A turbidity measurement of 0.58 NTU indicates water with high clarity.

3.1.2 Reflectors

The Doppler shift principle requires particles in the water to serve as reflectors for sound waves. The clear water used in the UWRL contains considerably fewer particles than sewage. Since it was not practical to replicate the particulate concentrations of normal sewage, coffee creamer was added to the water in small quantities on some test runs. The vendor maintains that although the coffee creamer additive did provide a level of reflectivity, the particulate concentration in the test water did replicate that of sewage, and thus could be a source of measurement error. It was not necessary to add creamer while the laboratory was making reference measurements.

During certain test configurations where particulate levels were especially low, ADS technicians compensations during confirmations by changing adjustable parameters on the ADS 4000 velocity subsystem. This sensitivity adjustment was made using the Fieldscan standard field configuration software. It allowed the meter to register the faint echoes from the few particles that were in the fastest portion of the flow, and adequately compensated for the clarity issue. In typical sewer installations, this type of adjustment is not necessary.

3.1.3 Laboratory Test Instrumentation

The laboratory instruments used during the verification tests are outlined in this section. Calibration records for the instruments are shown in Appendix A.

3.1.3.1 Flow Measurement Tanks and Calibrated Flow Meters

Laboratory weigh tanks and master venturi meters were used to determine the reference flow rate for each test run. The measurement tanks are directly traceable to the National Institute of Standards and Technology (NIST) by weight. The master venturi flow meters are regularly calibrated and are NIST-traceable. Uncertainty for the tanks and flow meters is less than 0.25 percent.

3.1.3.2 Precision Point Gauge

A precision point gauge was used as the reference depth measurement in determining the depth of flow near the test flow meter focal point (Figure 3-7). The precision point gauge is readable to the nearest one-thousandth of a foot. The point gauge was mounted as close as possible to the downstream edge of the access hole. Likewise, the ADS depth sensor was also mounted as close as possible to the downstream edge of the access hole. The reference depth measurement was compared to the indicated depth measurement from the meter.

3.1.3.3 Thermometer

A calibrated thermometer was used to measure the temperature of the water flowing through the test pipe. The temperature measurement was used for spreadsheet calculations requiring temperature. The thermometer was calibrated for accuracy before the verification tests.

Figure 3-7. The reference depth point gauge.

3.1.3.4 Timer

A calibrated stopwatch/timer was used to measure the collection time of the water entering the weigh tanks. The time measurement was used with the weight reading to calculate the actual flow rate for each test in which the master venturi meters were not used. The timer was calibrated before the verification tests.

3.1.3.5 Precision Calipers

Precision calipers were used to measure the inside diameter of the model piping and to verify the roundness of the pipe. An accurate measurement of each pipe diameter was necessary for correct area calculations.

3.1.4 Pretest Procedures

The VTP included a detailed set of test procedures that was followed during the verification tests. The procedures were consistent with the requirements established in the protocol. Laboratory personnel performed the following tasks before beginning the verification test on a specific pipe set-up.

- The geometry of the test pipe and location of the vendor instrument within the pipe was measured and documented.
- A digital photograph was taken of the installed flow meter sensors in each pipe size (see Figures 2-2, 3-7, 3-8, and 3-9).
- The time required for flow meter installation and set-up by the vendor was recorded.

3.1.5 General Test Procedures

Flow, depth, and velocity data from the test flow meter was logged electronically as recorded by the vendor-supplied electronics. Average recorded values were inputted into a computer spreadsheet.

Tables 3-1, 3-2, and 3-3 define each run that was tested in 10-, 20-, and 42-inch pipe, respectively.

The procedures described in this section were conducted for each set of test conditions established in Tables 3-1 through 3-3. The procedures were repeated each time the flow conditions were changed. The following procedural steps were taken for each run.

3.1.5.1 Set Flow Condition

Both the upstream and downstream control valves were used to set the flow. Uniform flow (free flow) tests had no downstream control. Conversely, the downstream control valve was throttled for submerged and backwater tests. Tables 3-1 through 3-3 list the target flow conditions for each run.

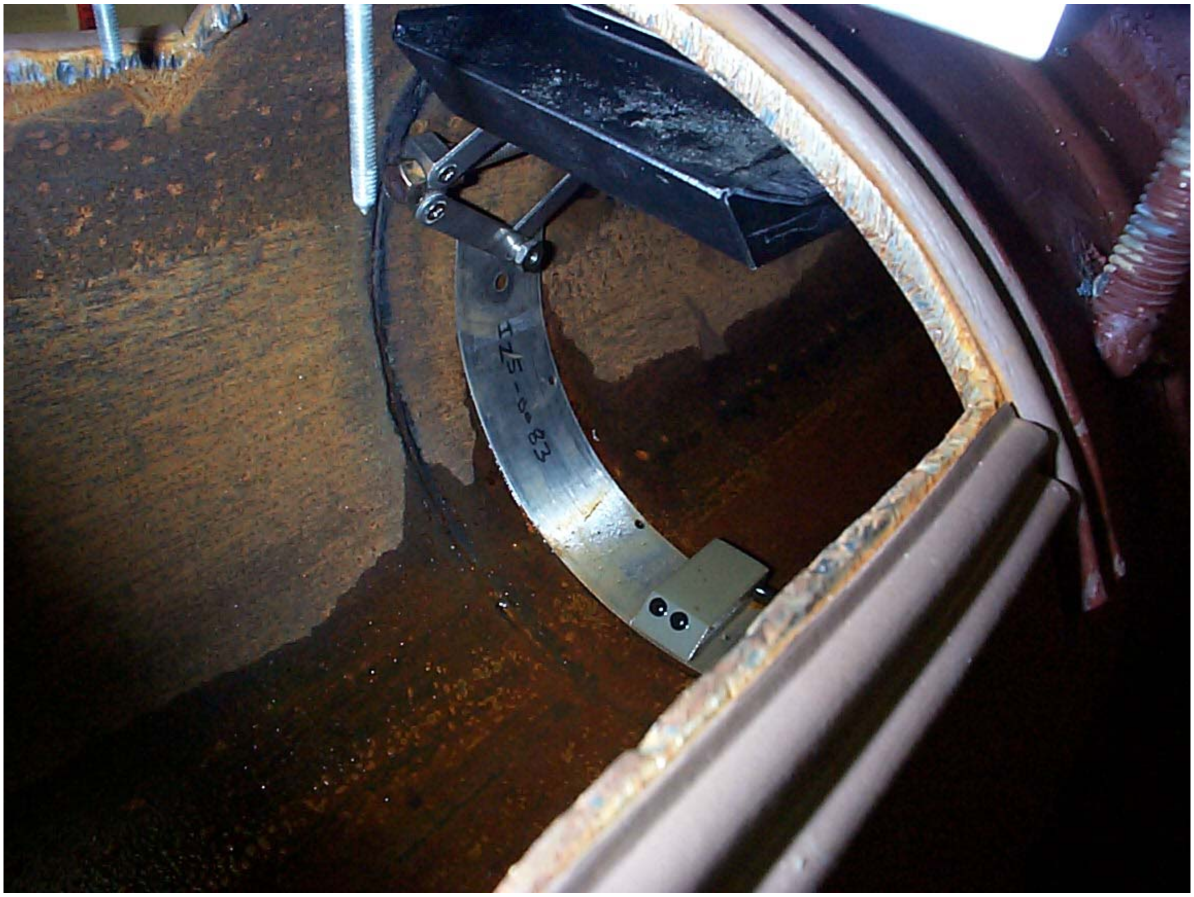


Figure 3-8. ADS flow monitoring sensors (laboratory 10-inch pipe installation).

3.1.5.2 Allow Flow To Stabilize

Test measurements were not made until the water had stabilized in the pipe. The flow was stabilized when the depth in the pipe did not change over time. The precision point gauge mounted on the centerline of the flow path acted as a gauge for setting and stabilizing the flow. The flow depth was set within .02 D (D = diameter of the pipe) of the flow depths specified in Tables 3-1 through 3-3.

3.1.5.3 Measure Water Temperature

The temperature of the water in the test pipe was measured using a calibrated mercury thermometer. This manual reading was recorded after the mercury in the thermometer had stabilized.

3.1.5.4 Measure Reference Flow

The reference flow rate was measured and recorded using the laboratory instrumentation before and after each logging period. Laboratory personnel measured the actual flow rate using the laboratory master flow meters. The master venturi flow meters are used often and are regularly calibrated at the laboratory. Flows too small to be accurately measured by the master venturi meters were measured using the laboratory weigh tanks.

Figure 3-9. ADS flow monitoring sensors (laboratory 42-inch pipe installation).

3.1.5.5 Measure Reference Depth

The actual depth was measured and recorded before and after the logging period of each run. Laboratory personnel measured the actual flow depth at the centerline of the pipe. This measurement was made very near the focal point for the sensor depth measurement. The depth was determined by taking the difference between the water surface measurement and the reference pipe invert measurement made by the centerline point gauge.

If the water surface was mounded slightly at the measurement location, a measurement of the complete cross-sectional water surface profile was necessary to generate the correct flow area for mean velocity calculations. An evaluation of each water surface profile was performed to decide the necessity of conducting either a single centerline depth or a complete cross-sectional water surface profile. This check was made by comparing the depths at the centerline and near the wall of the pipe.

If the peak-to-peak difference in depth across the water surface profile was greater than 0.02 D inches, a complete cross-sectional water surface profile was necessary. A special adjustable point gauge was used to measure water surface depths at five equally spaced locations across the water surface. Since the water surface width changes with increased depth, the spacing and position for the five equally spaced point gauges also varied.

3.1.5.6 Log Meter Data

Average flow, depth, and velocity measurements were electronically logged and recorded from the ADS output device. ADS provided a laptop computer to retrieve the logged data. The logged data was manually entered into a desktop computer spreadsheet at the end of each day of testing.

Once the flow stabilized, and after recording the first reference depth and flow measurements, laboratory personnel logged data from the flow monitoring equipment. Data was recorded in accordance with the operational procedures provided by the vendor, except that average flow rate, depth, and velocity readings were logged and recorded at one-minute intervals over a five-minute period. Data was reported for each one-minute interval. ADS prepared the instrument so that each one-minute sample was independent and was not averaged with prior samples. The operational procedure and data-logging method devised and utilized by ADS is given in Appendix C.

3.1.5.7 Measure Reference Flow and Depth (Second Time)

After the ADS flow meter completed its logging cycle (during the five-minute period), the reference flow and reference depth measurements were repeated. This was done to ensure that the flow conditions had remained constant during the five-minute logging period.

3.1.5.8 Calculate Reference Velocity

Using the measured cross-sectional water surface profile, the flow area was calculated using a computer spreadsheet. The mean velocity for the test was calculated by dividing the flow area into the reference flow measurement. The mean velocity was based on the average reference depth and flow measurements for the run.

3.1.5.9 Record Observations

The flow conditions for each run were recorded. Appendix B contains the raw data and notes documented by laboratory personnel during the verification tests.

3.1.5.10 Review Reference Data

Once all pertinent reference data for a single run had been entered into the computer, the results were reviewed before the flow conditions were changed for the next run. If flow conditions changed during a logging period, the test run was repeated. A run was repeated if the difference between the flow measurements taken at the start and end of the logging period were greater than one percent of the lesser value. Before repeating any given run, the vendor technician and laboratory personnel came to agreement that flow conditions had changed.

After all measurements for the run had been made, the flow conditions were changed and a new run was started. Each step listed above was repeated for each run.

3.1.5.11 Download Meter Data

The data was retrieved from the meter at the end of each test day. The five flow rate, depth, and velocity readings for each run were manually entered into a computer spreadsheet. The average of all five one-minute samples was calculated and reported.

3.1.6 Test Conditions

3.1.6.1 Free Flow and Backwater Tests

Free flow conditions were established by setting the desired depth in the pipe with no downstream control. Partial backwater conditions were simulated, by closing the downstream control valve in the pipe. Each backwater test (nonuniform flow condition) had a corresponding uncontrolled flow test (uniform or free flow condition). The flow velocities for the backwater tests were set to approximately one-half the flow velocities for the uncontrolled tests by using the supply master venturi flow meters. No backwater tests were performed for slopes greater than 0.5 percent.

3.1.6.2 Full Pipe Tests (Manhole Surcharged)

For tests in which there was downstream control and the pipe was full and pressurized, the opening on the top of the pipe through which the sensor is accessed and point gauge readings taken was closed. The access opening was covered with a watertight lid (see Figure 3-7). During these tests, the depth of water (hydraulic grade line) was not measured. For runs where the pipe was full during surcharged conditions, this report indicates the pipe diameter as the flow depth.

The reference flow measurement was divided by the pipe area to determine mean velocity. Flow and velocity were compared, but no comparison of surcharged pressures were made. The ADS output indicated that the depth of flow in the pipe was equal to the diameter of the pipe. A piezometric measurement of the submergence was made and reported as an indication of the magnitude of submergence only, and not as a reference pressure measurement.

3.1.6.3 Silt Simulation Tests

A simulated deposit of silt or sediment in the bottom of the pipe was conducted during the 42-inch pipe tests. A rigid flat bed was installed in the bottom of the 42-inch pipe at a depth of three inches. The simulated fixed sediment bed was constructed of wood and extended five pipe diameters at a depth of three inches. A 5:1 smooth sloped transition was installed at the leading edge of the fixed bed to reduce turbulence.

ADS personnel adjusted installation of the flow measurement device so that it sat above the simulated silt bed. Runs were made as indicated in Table 3-3. Figure 3-10 shows the fixed bed in the bottom of the 42-inch pipe.

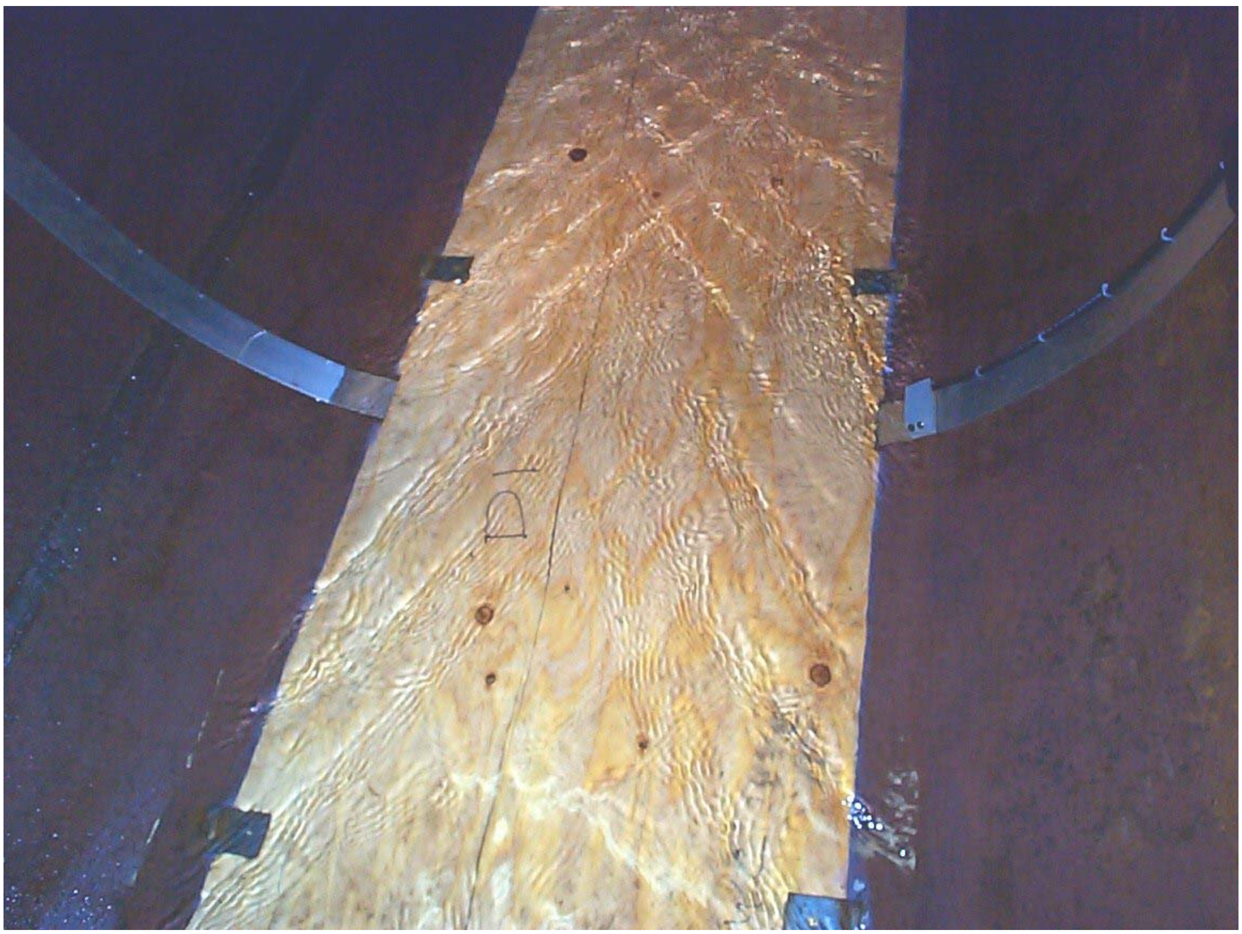


Figure 3-10. Simulation using a fixed bed (looking downstream).

3.1.6.4 Grease Build-up Tests

Tests were performed with thin layers of grease (Crisco) placed on all submerged components of the flow monitoring equipment. These tests evaluated the ability of the meter to continue functioning accurately when grease built up on the wetted components, and also allowed technicians to observe and record whether the grease remained on the components. Both a 0.5-mm and 2.0-mm layer of grease was tested under three different flow conditions (six runs). Runs were made as indicated in Table 3-3. Figure 3-11 shows the depth sensor with a thin layer of grease applied. The grease thickness in the photograph is 0.5 mm thick. The 2.0-mm tests had four times the thickness of grease, which was applied manually. Figure 3-11 shows the flow sensor after grease was applied.

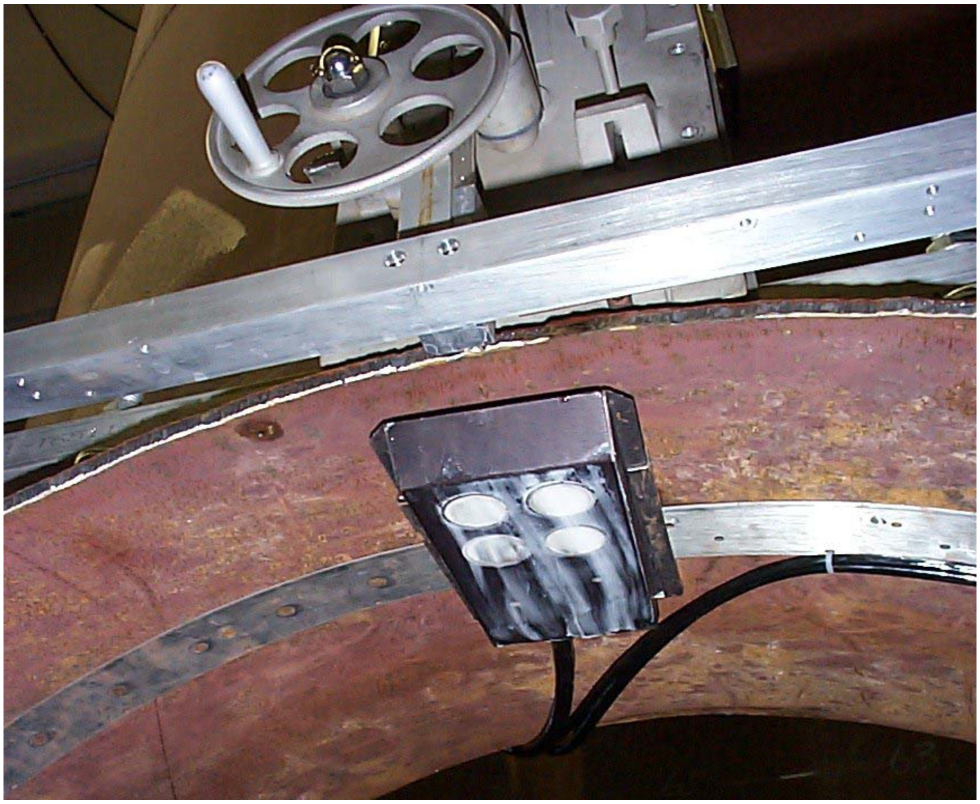


Figure 3-11. The 0.5-mm grease test. ADS depth sensor shown.

3.1.6.5 Reverse Flow Tests

A simulation of reversed pressure flow conditions was tested by elevating the test pipe to a slightly negative slope, installing the flow meter in the test line backwards, submerging the manhole, and forcing water uphill. The sensor was installed on the downstream side of the manhole (uphill side). Runs were made as indicated in Tables 3-1 and 3-2. Reverse flow tests were performed on the 10- and 20-inch pipes, but not the 42-inch pipe.

Table 3-1. Test Conditions and Sequence: 10-inch Test Pipe

Run number	Pipe slope (percent)	Water depth	Uniform flow (downstream-uncontrolled)	Nonuniform flow (downstream-controlled)
1	0.1	0.1 D	Yes	
2	0.1	0.3 D	Yes	
3	0.1	0.5 D	Yes	
4	0.1	0.8 D	Yes	
5	0.1	0.1 D		Yes
6	0.1	0.3 D		Yes
7	0.1	0.5D		Yes
8	0.1	0.8 D		Yes
9[a]	0.1	~1.5 D		Yes
10[a]	0.1	~2.5 D		Yes
11	0.5	0.1 D	Yes	
12	0.5	0.3 D	Yes	
13	0.5	0.5D	Yes	
14	0.5	0.8 D	Yes	
15	0.5	0.1 D		Yes
16	0.5	0.3 D		Yes
17	0.5	0.5D		Yes
18	0.5	0.8 D		Yes
19[a]	0.5	~1.5 D		Yes
20[a]	0.5	~2.5 D		Yes
21	1.25	0.1 D	Yes	
22	1.25	0.3 D	Yes	
23	1.25	0.5D	Yes	
24	1.25	0.8 D	Yes	
25[a]	1.25	~1.5 D		Yes
26[a]	1.25	~2.5 D		Yes
27	2.0	0.1 D	Yes	
28	2.0	0.3 D	Yes	
29	2.0	0.5D	Yes	
30	2.0	0.8 D	Yes	
31[a]	2.0	~1.5 D		Yes
32[a]	2.0	~2.5 D		Yes
33[b]	-0.1	~1.5 D		Yes
34[b]	-0.1	~2.5 D		Yes

[a] Manhole is surcharged.
[b] Flow meter installed backwards, pipe slope set negative, surcharged conditions.

Table 3-2. Test Conditions and Sequence: 20-inch Test Pipe

Run number	Pipe slope (percent)	Water depth	Uniform flow (downstream-uncontrolled)	Nonuniform flow (downstream-controlled)
1	0.1	0.1 D	Yes	
2	0.1	0.3 D	Yes	
3	0.1	0.5 D	Yes	
4	0.1	0.8 D	Yes	
5	0.1	0.1 D		Yes
6	0.1	0.3 D		Yes
7	0.1	0.5D		Yes
8	0.1	0.8 D		Yes
9[a]	0.1	~1.5 D		Yes
10[a]	0.1	~2.5 D		Yes
11	0.5	0.1 D	Yes	
12	0.5	0.3 D	Yes	
13	0.5	0.5D	Yes	
14	0.5	0.8 D	Yes	
15	0.5	0.1 D		Yes
16	0.5	0.3 D		Yes
17	0.5	0.5D		Yes
18	0.5	0.8 D		Yes
19[a]	0.5	~1.5 D		Yes
20[a]	0.5	~2.5 D		Yes
21	1.25	0.1 D	Yes	
22	1.25	0.3 D	Yes	
23	1.25	0.5D	Yes	
24	1.25	0.8 D	Yes	
25[a]	1.25	~1.5 D		Yes
26[a]	1.25	~2.5 D		Yes
27	2.0	0.1 D	Yes	
28	2.0	0.3 D	Yes	
29	2.0	0.5D	Yes	
30	2.0	0.8 D	Yes	
31[a]	2.0	~1.5 D		Yes
32[a]	2.0	~2.5 D		Yes
33[b]	-0.1	~1.5 D		Yes
34[b]	-0.1	~2.5 D		Yes

[a] Manhole is surcharged.

[b] Flow meter installed backwards, pipe slope set negative, surcharged conditions.

Table 3-3. Test Conditions and Sequence: 42-inch Test Pipe

Run number	Pipe slope (percent)	Water depth	Uniform flow (downstream-uncontrolled)	Nonuniform flow (downstream-controlled)
1	0.2	0.1 D	Yes	
2	0.2	0.3 D	Yes	
3	0.2	0.5 D	Yes	
4	0.2	0.8 D	Yes	
5	0.2	0.1 D		Yes
6	0.2	0.3 D		Yes
7	0.2	0.5D		Yes
8	0.2	0.8 D		Yes
9[a]	0.2	~1.5 D		Yes
10[a]	0.2	~2.5 D		Yes
11[b]	0.2	0.1 D		Yes
12[b]	0.2	0.7 D		Yes
13[b]	0.2	~1.5 D		Yes
14[c]	0.2	0.1D	Yes	
15[c]	0.2	0.3D	Yes	
16[c]	0.2	0.8D	Yes	
17[d]	0.2	0.1D	Yes	
18[d]	0.2	0.3D	Yes	
19[d]	0.2	0.8D	Yes	

[a] Manhole is surcharged.
[b] Silt simulation test.
[c] Grease build-up test with 0.5-mm grease layer.
[d] Grease build-up test with 2.0-mm grease layer.

3.1.7 Data management and analysis

All raw data, notes, observations, and test descriptions were recorded using Microsoft Excel. Reference values for flow, depth, and velocity were calculated for each test run. These reference values provided the basis for determining the accuracy of the values from the flow meter output.

The reference flow value for each run was the arithmetic average of the flow at the beginning and at the end of the logging period, as determined using the calibrated master venturi meter or weigh tank.

The reference depth value for each run was the arithmetic average of the depth at the beginning and at the end of logging period, as determined using precision point gauges.

The reference velocity value for each run was the arithmetic average of the velocity values calculated from the depth and flow measurements taken at the beginning and end of the logging period.

Meter output of flow, depth, and velocity was recorded in the Microsoft Excel spreadsheet for each of the five one-minute samples. When no data was available, the one-minute sample field was left blank. An average of the five one-minute samples was made to indicate the five-minute average for the meter.

3.1.8 Quality Assurance

The Utah State University Research Foundation has an active quality control program at UWRL. Flow meter manufacturers and nuclear power plants regularly audit the laboratory for quality assurance. Under the laboratory quality assurance program, equipment is calibrated for accuracy on a scheduled cycle or occasionally as-needed. Instrumentation calibrations are normally subcontracted to outside organizations, although some are performed using the calibration facilities at the laboratory itself. Where applicable, calibrations indicate traceability to NIST. All laboratory instrumentation that was used during this testing program was calibrated prior to performing verification tests. Calibration sheets for all applicable instrumentation are provided in Appendix A. The laboratory master venturi flow meters were used during most of the test program as the reference flow measurement. These venturi meters have uncertainties less than 0.25 percent, which falls within the desired accuracy for the measurement.

3.2 Test Results

3.2.1 Preliminary Test Measurements

Prior to each test series the geometry of the test pipe and location of the vendor instrument within the pipe were measured and documented. Figures 3-1 through 3-3 show pipe lengths and manhole and riser dimensions. Figure 3-12 shows the size and location of the access hole in each of the three test set-ups and establishes the location of the ADS stainless steel mounting ring for each test set-up. Tables 3-4 through 3-6 summarize the preliminary information recorded for each pipe size. The reference inside-pipe-diameter measurements were made using precision calipers at the location in the pipe where the flow meter sensors were installed. Measurements were made in four directions and averaged (every 45 degrees). Only three measurements were made in the 10-inch pipe because it was quite round. The time required to install and set up the flow meter was also recorded.

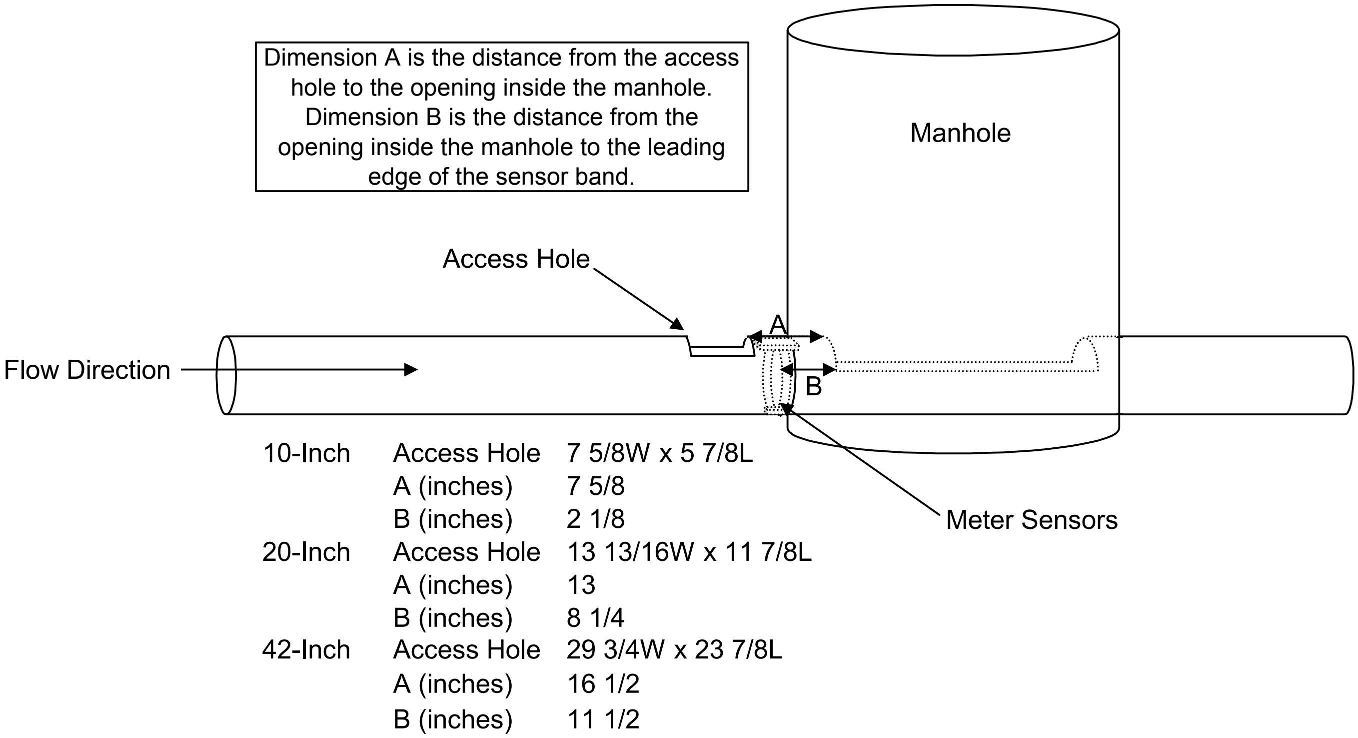


Figure 3-12. Sensor installation locations.

Table 3-4. Preliminary 10-inch Test Measurements

Meter (monitor) serial number:	02527
Ultrasonic serial number:	16405
Velocity sensor serial number:	11652
Pressure transducer serial number:	8710
Test size:	10-inch
Test dates:	5/2/01 to 5/11/01
Sensor location U.S. of manhole opening:	2.125 in.
Straight pipe U.S. of manhole:	63.9 ft
Straight pipe D.S. of manhole:	28.7 ft
Three pipe inside diameter measurement:	10.285 in., 10.29 in., 10.27 in.
Average pipe inside diameter:	10.282 in.
ADS pipe diameter measurement:	10.250 in.
Pipe invert point gauge reference:	1.731 ft
Time required to install the sensor:	15 min
Time required to set up the sensor:	90 min
Calibration performed by:	Steven Barfuss, Randy Geldmacher, Tyler Smith
Vendor technicians:	Keith Waites, Christy Kennamer

Table 3-5. Preliminary 20-inch Test Measurements

Meter (monitor) serial number:	02527
Ultrasonic serial number:	16405
Velocity sensor serial number:	11652
Pressure transducer serial number:	8710
Test size:	20-inch
Test dates:	5/30/01 to 6/4/01
Sensor location U.S. of manhole opening:	8.25 in.
Straight pipe U.S. of manhole:	74.0 ft
Straight pipe D.S. of manhole:	17.6 ft
Four pipe inside diameter measurement:	19.435 in., 19.555 in., 19.615 in., 19.553 in.
Average pipe inside diameter:	19.535 in.
ADS pipe diameter measurement:	19.500 in.
Pipe invert point gauge reference:	0.907 ft
Time required to install the sensor:	30 min
Time required to set up the sensor:	120 min
Calibration performed by:	Steven Barfuss, Randy Geldmacher, Tyler Smith
Vendor technicians:	Jeffrey White, Heather Hackett

Table 3-6. Preliminary 42-inch Test Measurements

Meter (Monitor) Serial Number:	02527
Ultrasonic Serial Number:	16405
Velocity Sensor Serial Number:	11652
Pressure Transducer Serial Number:	8710
Test Size:	42-nch
Test Dates:	5/30/01 to 6/4/01
Sensor Location U.S. of manhole opening:	11.5 in.
Straight Pipe U.S. of manhole:	84.0 ft
Straight Pipe D.S. of manhole:	36.6 ft
Four Pipe Inside Diameter Measurement:	3.424 ft, 3.455 ft, 3.437 ft, 3.448 ft
Average Pipe Inside Diameter:	3.441 ft
Average Pipe Inside Diameter:	41.292 in.
ADS Pipe Diameter Measurement:	41.250 in.
Pipe Invert Point Gauge Reference:	-0.100 ft
Time required to install the sensor:	60 min
Time required to set up the sensor:	150 min
Calibration Performed by:	Steven L. Barfuss, Randy Geldmacher, Tyler Smith
Vendor Technicians:	Erica Blanken, Gillian Woodward

3.2.2 *Test Data*

The data obtained during testing was compiled in both graphical and statistical formats. The graphs are presented in the following sections, while the statistical tables are included in Appendix D. The time listed for each run in the statistical tables represents the start time for the five-minute logging period. This recorded time was critical to the success of the tests since the logged data was retrieved some time after the run was finished. It was necessary to find the recorded start time in the logged data to retrieve the corresponding set of five flow, depth, and velocity readings. For this reason, the times for the UWRL computer and the laptop computer used to log the data from the ADS flow meter were synchronized each day.

For each run, the data include the pipe slope, desired flow condition, and the date and time when the five-minute logging period occurred. Up to five depth measurements were made for each logging period. It was usually not required to make all five depth measurements since the transverse water surface profiles were normally quite flat. During submerged tests, the depth readings in the tables in Appendix D show "FP," indicating that the pipe was running full.

Select runs were either not practical or not possible, and are indicated by "NA" in the appendix data tables in Appendix D. In some cases, the meter did not record data during a particular one-minute interval or a reference depth reading was not made, and hyphens (-) were placed in the table when no data was collected. ADS was allowed to re-test certain runs due to changes in the test protocol subsequent to the original tests. An "R" following the run number indicates these runs in the data tables.

3.2.2.1 Statistical Data Evaluation

Deviation is summarized by the various test configurations in Table 3-7. Deviation is calculated as the mean of the percentage deviation for each given category. Depth, velocity, and flow data for each test run is outlined in Appendix D.

The tables also contain the 95-percent confidence interval for the deviation data. The equation used to establish the confidence bounds is:

$$\text{Confidence} = \bar{x} \pm \left(t \times \left[\frac{s}{\sqrt{n}} \right] \right)$$

Where:

$\bar{x}$ = sample mean
s = standard deviation
n = sample size
t = Student's t-distribution with $(n-1)$ degrees of freedom

Therefore, the width of the interval is a function of not only the variation in instrument deviation, but also the number of test runs in each reported category. In general, the categories with the greatest number of runs will show the narrowest confidence intervals.

Table 3-7. Deviation by Test Configuration: Normal Operating Conditions

Pipe size (inches)	Deviation (percent)	95-percent confidence interval
10	4.7	-6.5 – 15.8
20	-0.7	-7.9 – 6.6
42	-0.9	-10.8 – 9.0
Pipe slope (percent)		
0.1	4.7	-4.2 – 13.5
0.2	-0.9	-10.8 – 9.0
0.5	-0.8	-10.9 – 9.4
1.25	2.3	-10.8 – 15.4
2.0	0.2	-30.1 – 30.4
Percent full (d/D, percent)		
10	-0.1	-22.2 – 20.3
30	1.1	-13.5 – 15.8
50	5.4	-1.6 – 12.5
80	1.9	-7.4 – 11.2
150	-4.6	-28.8 – 19.6
250	3.3	-6.7 – 13.2
Condition		
Free flow	2.7	-4.3 – 9.7
Backwater	0.2	-7.5 – 8.0
All normal conditions	1.2	-4.0 – 6.5

The ADS 4000 was tested under "abnormal conditions," earlier defined previously as tests where grease is applied to the depth sensor and reverse flow conditions. During the tests where 0.5 mm of grease was applied to the ultrasonic depth sensors, the mean deviation was 1.3 percent. When 2.0 mm of grease was applied to the ultrasonic depth sensors, the mean deviation at 69.5 percent. The mean deviation for reverse flow tests was –62.4 percent.

3.2.2.2 Graphical Evaluation of All Flow Data

The overall accuracy of the ADS flow meter under normal operating conditions is shown in Figure 3-13, the plot of measured flow rates versus the laboratory reference. This plot excludes tests where grease was applied to the sensors and tests with reverse flow.

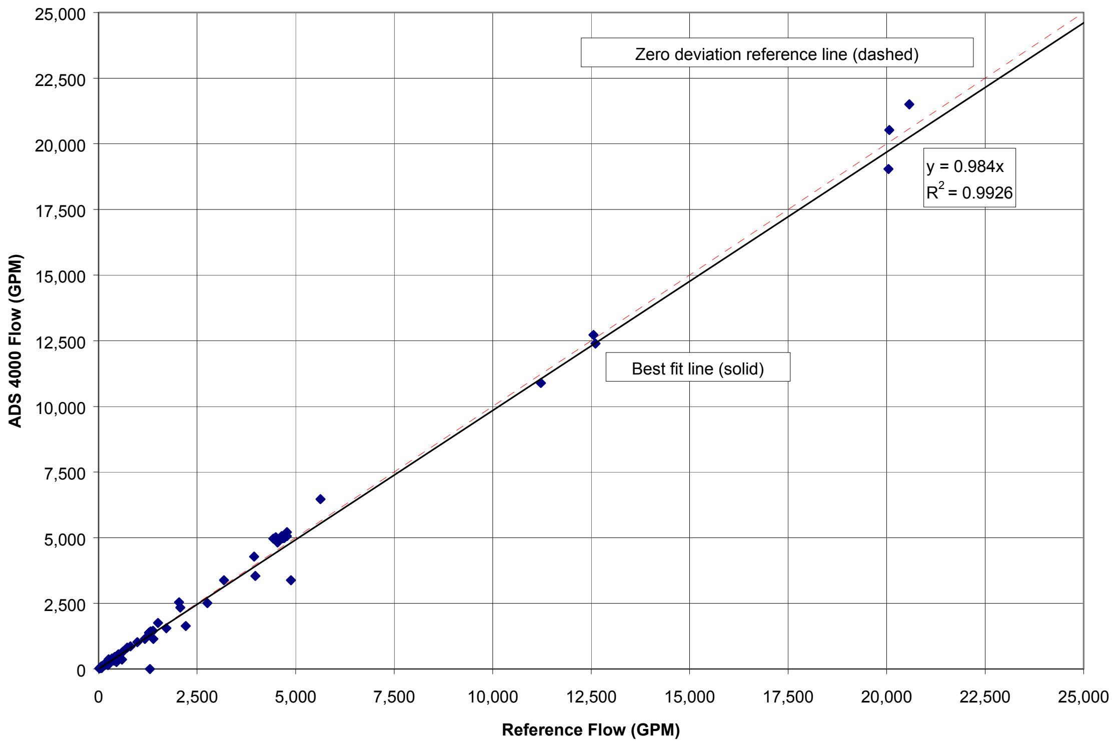


Figure 3-13. Metered flow rate versus reference flow rate.

Figure 3-13 was generated using formulas available in Microsoft Excel for characterizing a linear trend line. The line is fitted through the origin (y-intercept of zero). The slope of the regression line is computed as:

$$\text{slope} = \frac{\sum xy}{\sum x^2}$$

where:
x = reference flow rates
y = ADS flow rates

The correlation coefficient, r^2, is defined as:

$$r^2 = 1 - \frac{\text{SSE}}{\text{SST}}$$

where:
SSE is the sum of squares for the error component
SST is the sum of squares total.

With the slope and correlation coefficient, bias and precision can be calculated. Bias and precision are expressed as functions of the slope and correlation coefficient, respectively, using the following equations:

$$\text{bias} = \left(1 - \frac{\text{slope of zero deviation reference line}}{\text{slope of best fit line}}\right) \times 100\%$$

$$\text{precision} = \left(1 - \frac{r^2 \text{ of zero deviation reference line}}{r^2 \text{ of best fit line}}\right) \times 100\%$$

Values of 1.0 for both slope and correlation coefficient would yield results of zero percent for both bias and precision, and would indicate a one-to-one relationship between the metered flow and the reference flow with changes in the reference flow accounting for all of the variation in the metered flow.

Evaluation of the ADS 4000 data for the three pipe sizes (10-inch, 20-inch, and 42-inch) under normal operating conditions yields a bias of 1.6 percent and precision of 0.74 percent.

3.2.2.3 Graphical Evaluation of Flow Data by Test Condition

The flow, depth, and velocity readings, in addition to the average of the readings, are compared to the average reference flow, depth, and velocity for each run. The average reference flow, depth, and velocity are equal to the mathematical average of the initial and final reference measurements made for each run.

The graphical evaluation of the flow data by test condition is provided in Tables 3-15 through 3-32. The free flow and backwater data have been noted in each figure. The scatter-graph figures for slopes of 0.1 and 0.5 percent have both free flow and backwater data shown on the same figure. Scatter-graph figures for pipe slopes of 1.25 and 2.0 percent do not show backwater data because none was collected for these slopes. It should be noted that the free flow curves are not always smooth. Laboratory personnel attempted to eliminate all backwater effects during free flow tests, but in some cases were not able to completely eliminate the effect of the valve downstream of the test pipe. As an example, Figure 3-16 shows the free flow curve dropping off on the upper end. This shows that the velocity was lower than the desired free flow condition, indicating. some backwater effect. Even though this occurred periodically, it did not affect the test results, since the verification is a direct comparison between the reference measurements and the meter data regardless of the flow condition.

Two sets of plots are presented for each pipe size illustrating the deviation from reference flow. One set of plots (Figures 3-17, 3-23, and 3-29) show deviation as percent of reference across the full range of reference flows. Another set of plots (Figures 3-18, 3-24, and 3-30) show flow meter quantities compared to reference quantities. The reference line is the point of equality between the ADS flow meter and the reference measurements, where the deviations between the two would be zero. The slope and correlation coefficient of the best-fit line are measures of bias and precision, respectively, where 1.0 is the ideal value.

For the tests performed in the 10-inch pipe, Figures 3-15 through 3-18 are scatter-graph plots of the free flow and backwater tests, Figure 3-19 shows the deviation from the reference flow, and Figure 3-20 is a plot of reference flow versus meter flow.

For the tests performed in the 20-inch pipe, Figures 3-21 through 3-24 are scatter-graph plots of the free flow and backwater tests, Figure 3-25 shows the deviation from the reference flow, and Figure 3-26 is a plot of reference flow versus meter flow for all tests.

For the tests performed in the 42-inch pipe, Figures 3-27 through 3-30 are scatter-graph plots of the free flow and backwater tests, Figure 3-31 shows the deviation from the reference flow for all tests, and Figure 3-32 is a plot of reference flow versus meter flow.

3.2.2.4 Data Analysis Discussion

The protocol outlines the procedure for characterizing flow meter accuracy by calculating deviation using the following formula:

$$\text{percent deviation } (\%D) = (X_M - X_R) / X_R \times 100\%$$

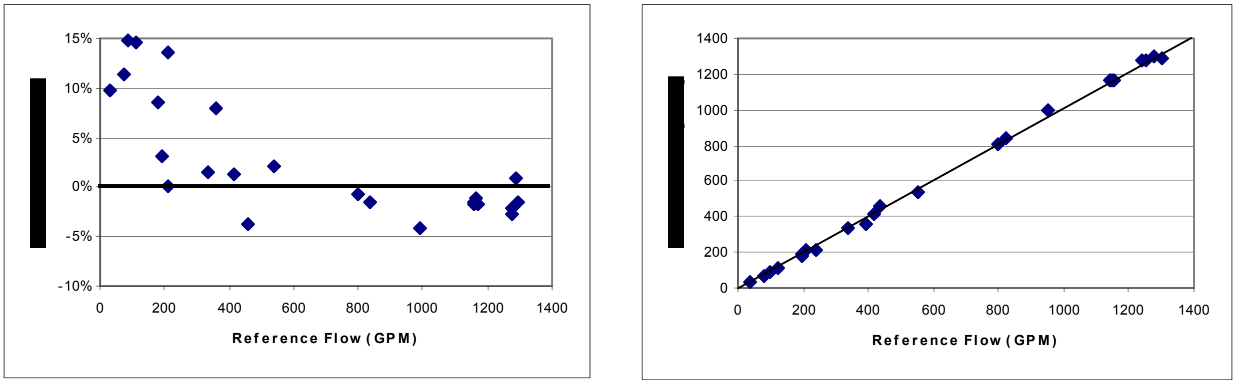
Where:

X_M = mean value recorded by test flow meter
X_R = mean reference value

Calculating deviation as a percent of the reference value can exaggerate the apparent deviation at low flows. During low flow conditions, a low absolute $|X_M - X_R|$ deviation results in a high percent (%D) deviation, creating a disproportionate percent deviation bias at low flow conditions.

For example, during the ADS 4000 tests with the 10-inch pipe, test run number 16 recorded a test flow meter reading of 99.47 gallons per minute (gpm) and a reference reading of 73.81 gpm. This results in an absolute deviation of 25.66 gpm but a percent deviation of 34.76 percent. By contrast, test run number 19, which had the highest reference reading for the 10-inch pipe tests at 1,320.25 gpm, had a corresponding test flow meter reading of 1,421.76 gpm, which computes to a larger absolute deviation (101.51 gpm) when compared to test run 16 but a much lower percent deviation (7.69 percent).

This phenomenon can also be represented graphically. Evaluating the ADS 3600 10-inch pipe test runs with an arbitrary "low flow" range of 0–600 gpm, the same data can be expressed on two separate plots: absolute deviation and percent deviation. When this is done, the absolute deviation data shows a strong correlation in absolute terms despite the relatively high percent deviation, as shown in Figure 3-14 below.



(a) Absolute deviation **(b) Percent deviation**

Figure 3-14. ADS 4000 data summary, 10-inch pipe, 0–600 gpm reference flow.

The percent deviation data is presented in the ETV verification report because it is a common statistical method of computing the difference between a measured value and a reference value. This statistical anomaly is presented to inform the end-users of flow monitoring equipment that using percent deviation data when evaluating the performance of flow monitoring equipment at low flows may result in misleading information. During low flow conditions, a flow meter can report flow very close to a reference or actual flow but can be off by a disproportionately high percent deviation, especially when compared against high flow condition data. This phenomenon is reflective of a statistical limitation rather than a flow meter limitation.

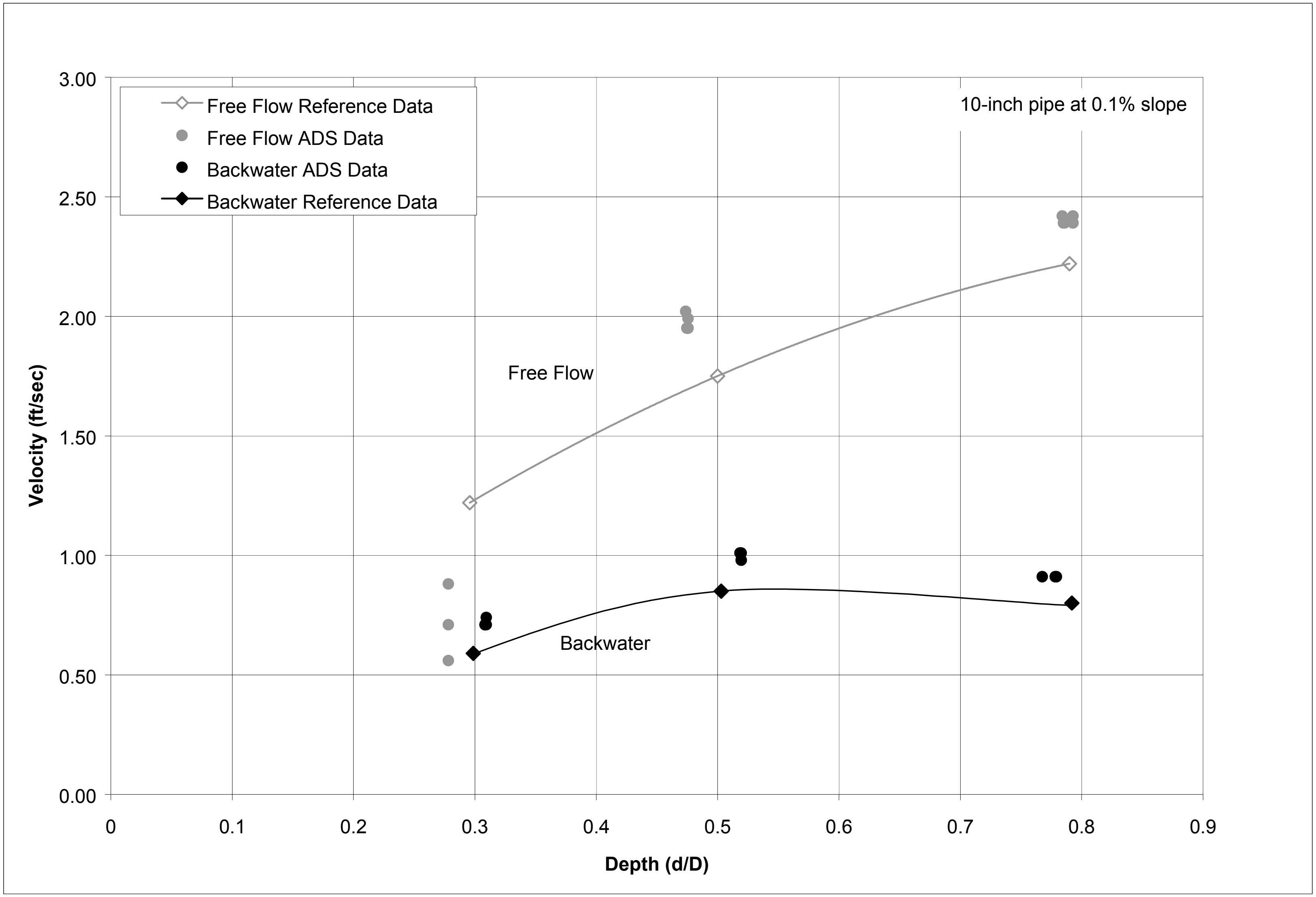


Figure 3-15. Scatter-graph for 10-inch pipe at 0.1 percent slope.

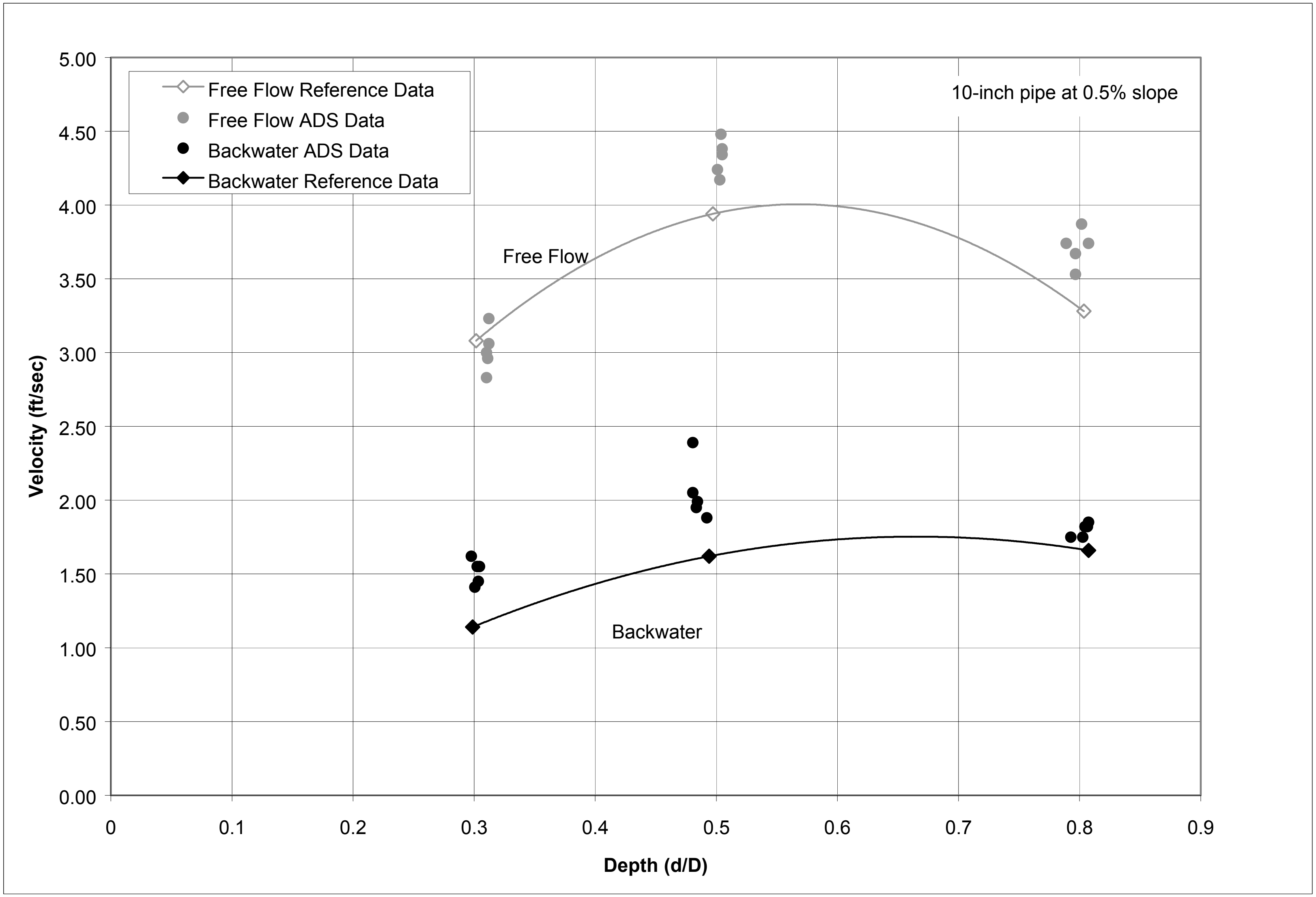


Figure 3-16. Scatter-graph for 10-inch pipe at 0.5 percent slope.

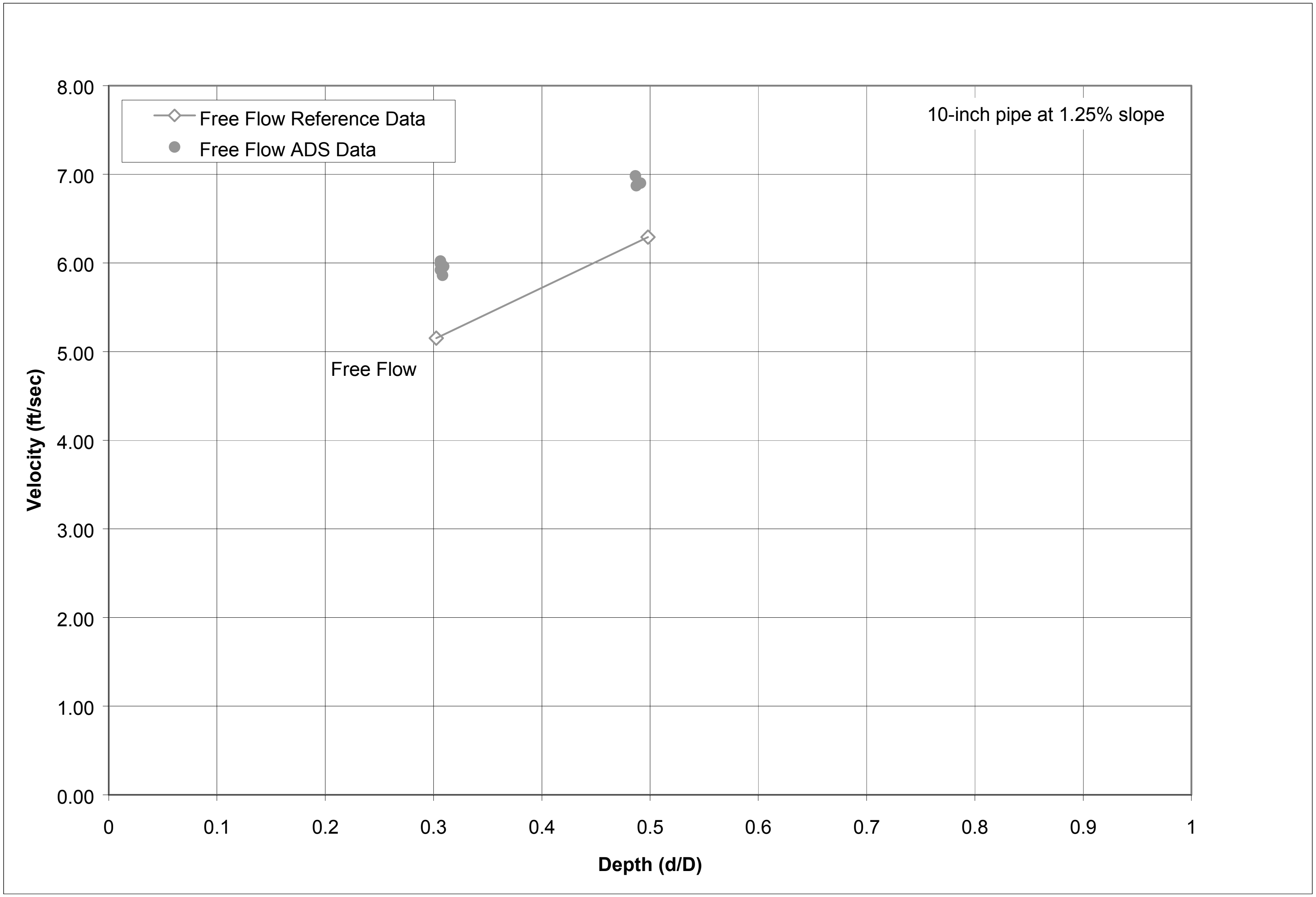


Figure 3-17. Scatter-graph for 10-inch pipe test at 1.25 percent slope.

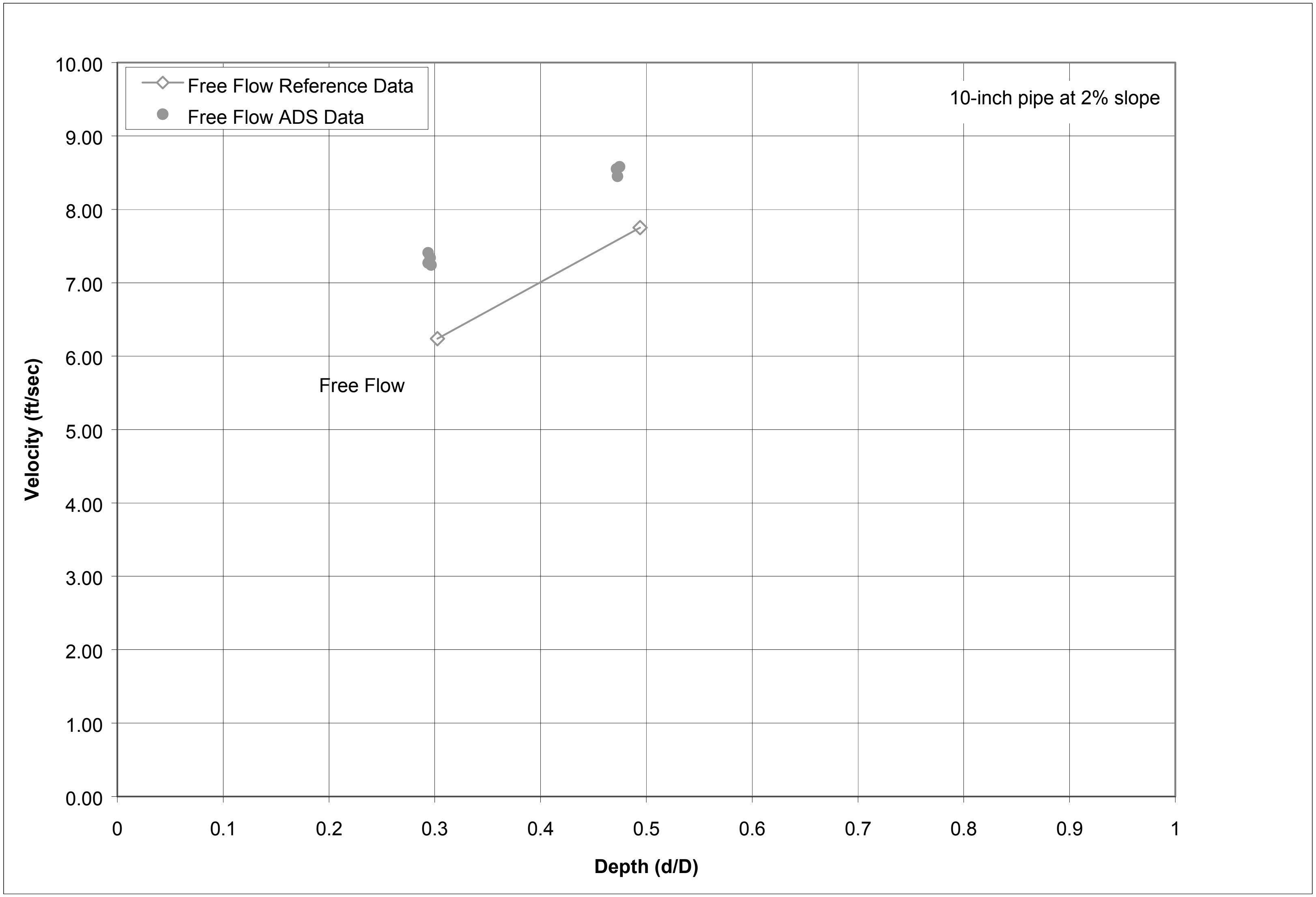


Figure 3-18. Scatter-graph for 10-inch pipe at 2.0 percent slope.

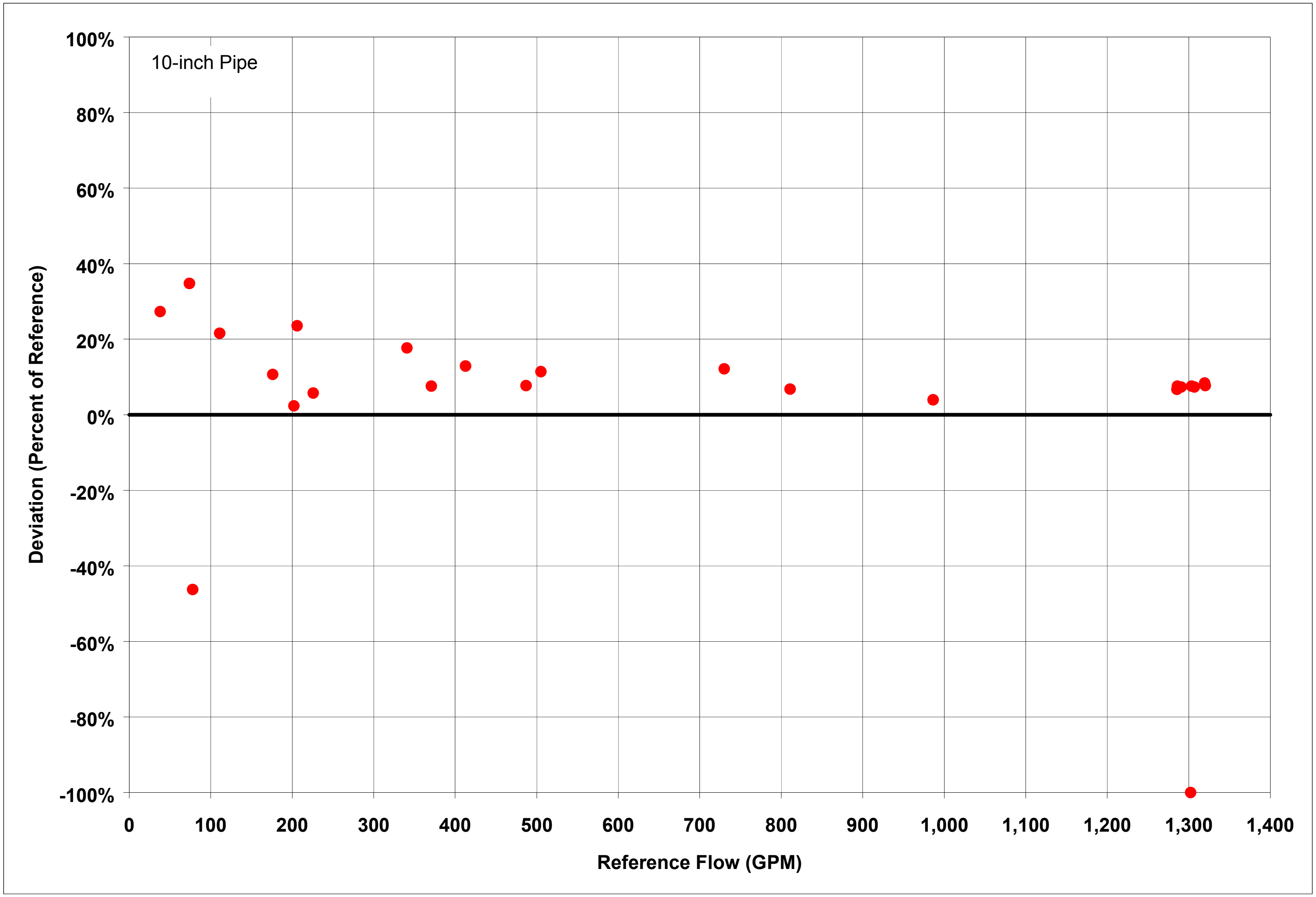


Figure 3-19. Deviation of meter flow to reference flow for 10-inch pipe.

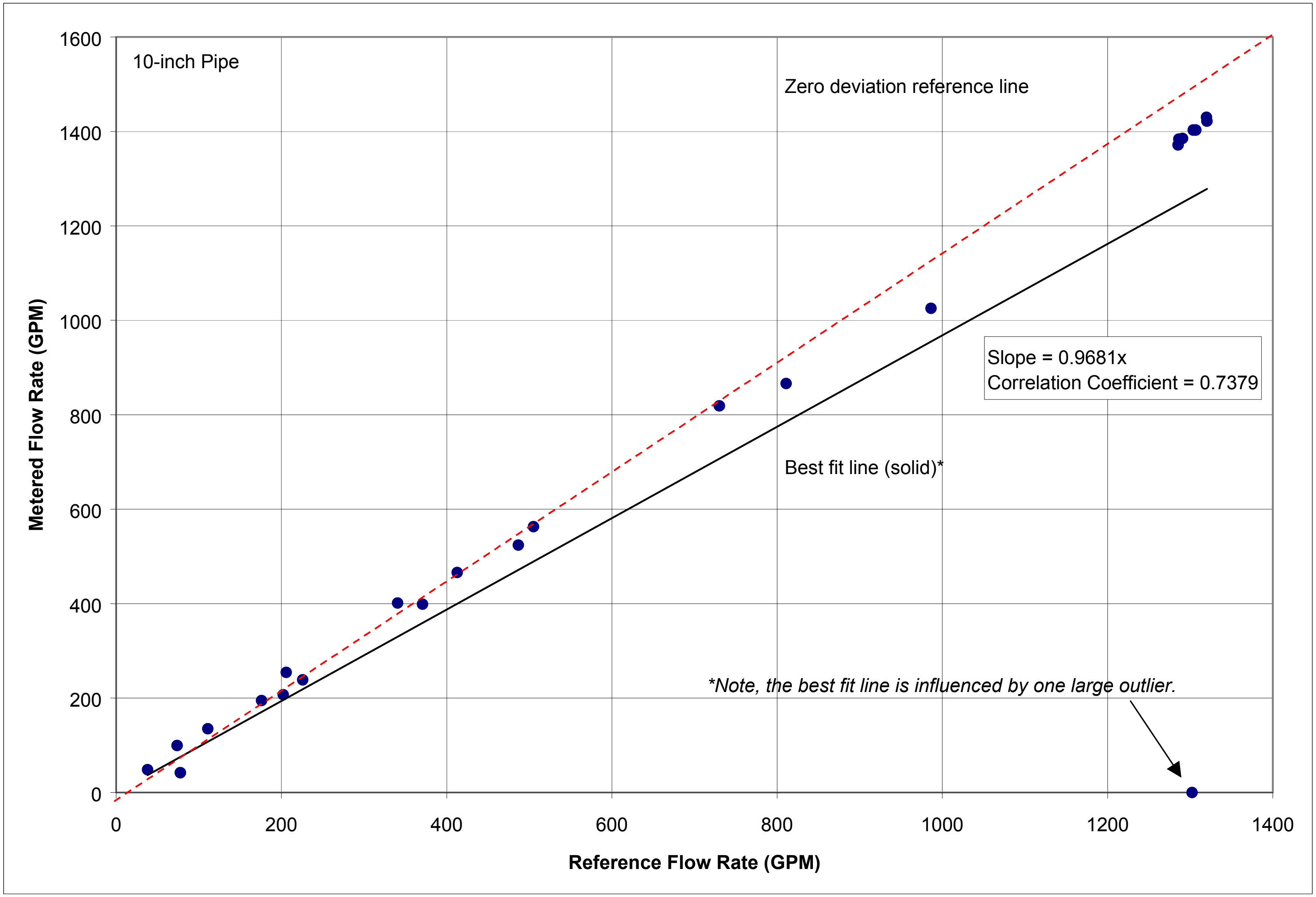


Figure 3-20. Plot of reference flow versus meter flow in 10-inch pipe.

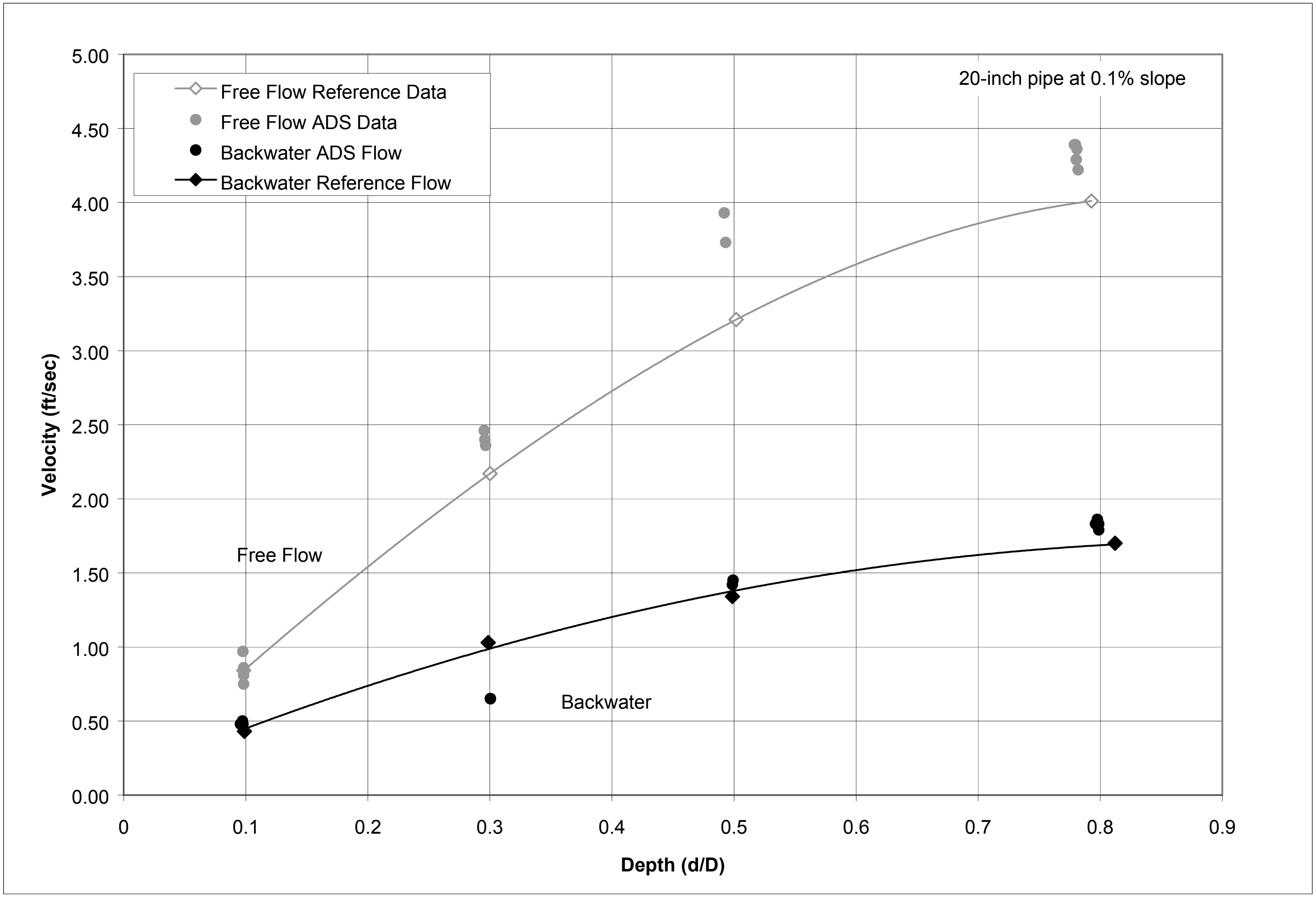


Figure 3-21. Scatter-graph for 20-inch pipe test at 0.1 percent slope.

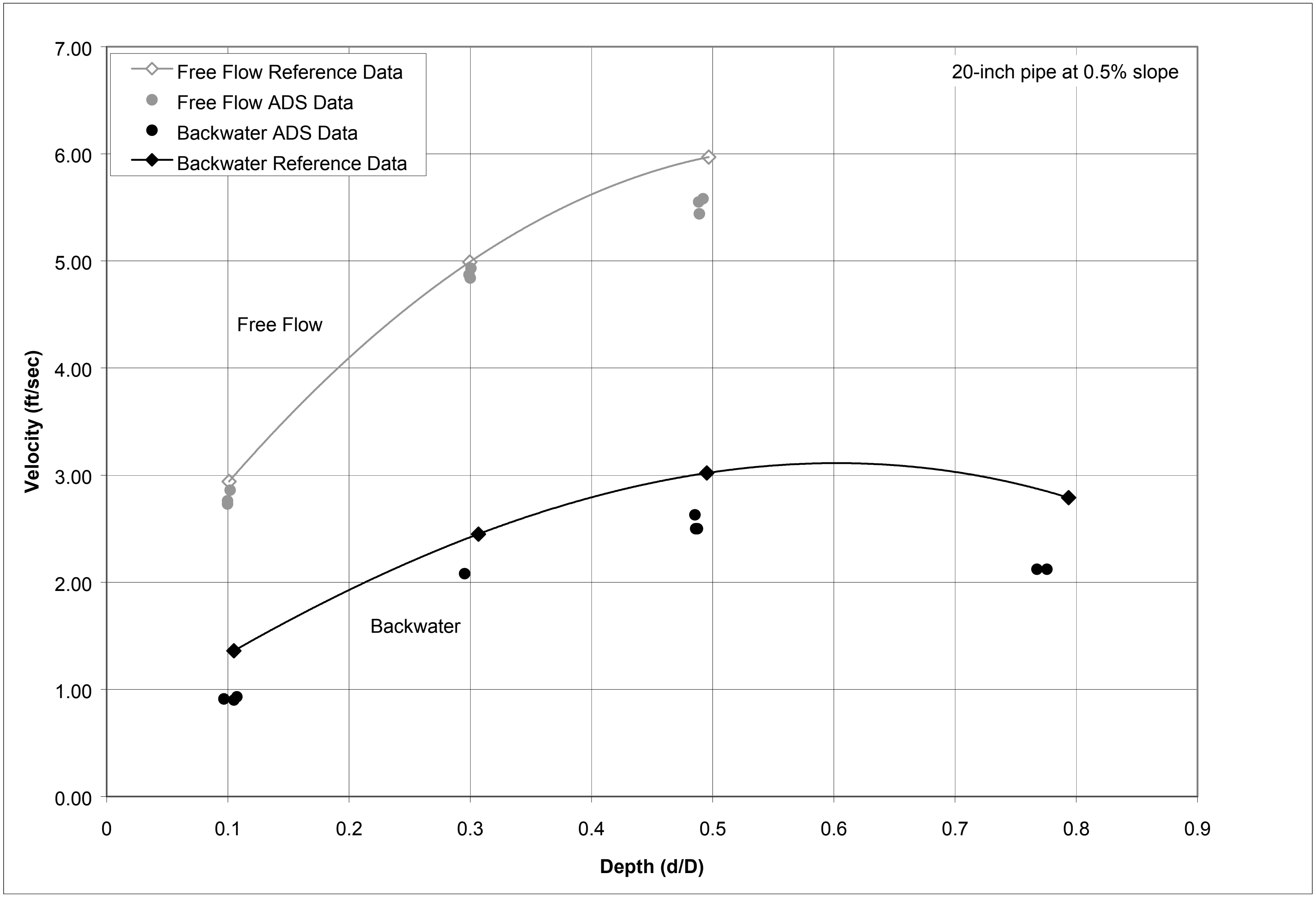


Figure 3-22. Scatter-graph for 20-inch pipe at 0.5 percent slope.

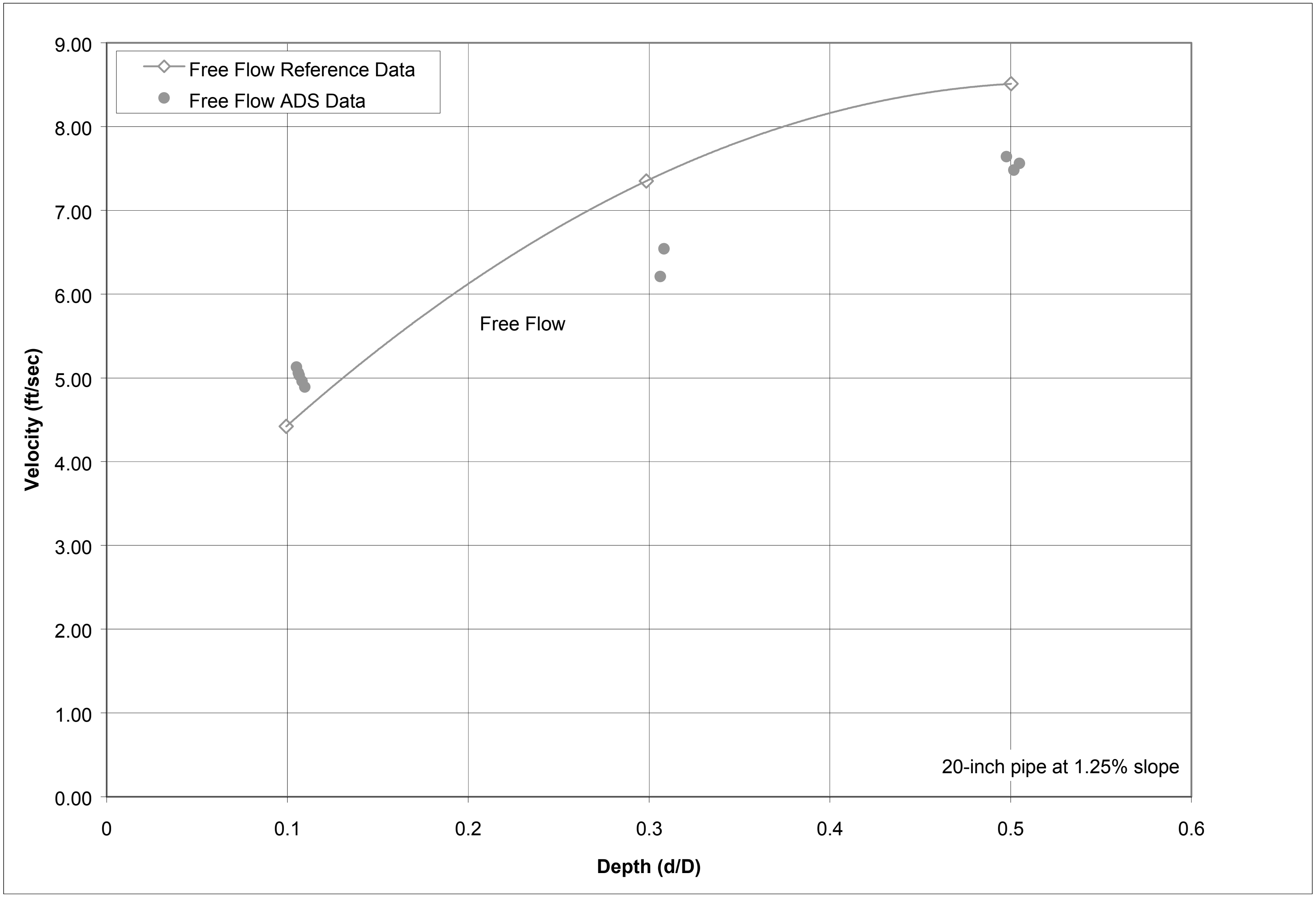


Figure 3-23. Scatter-graph for 20-inch pipe at 1.25 percent slope.

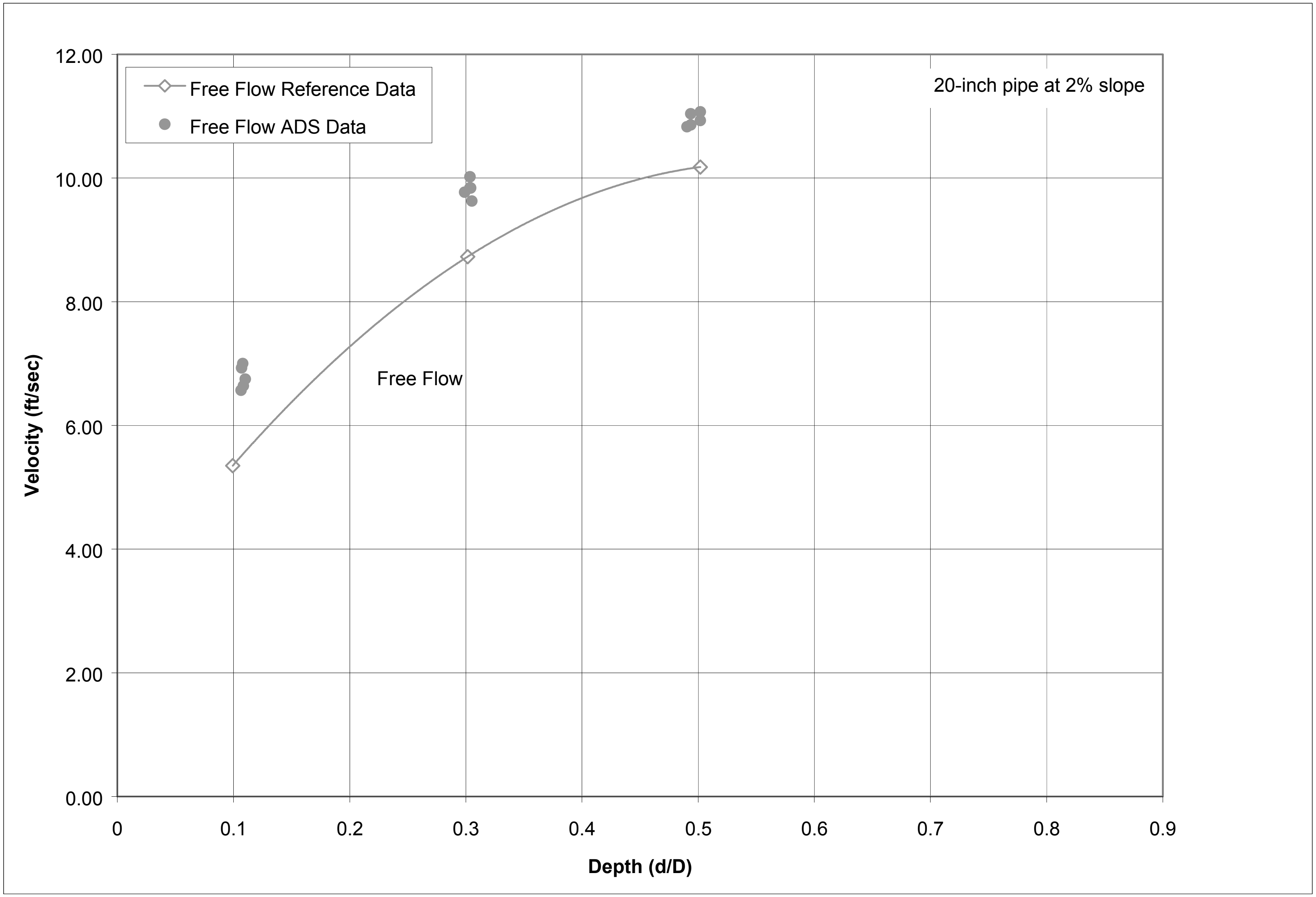


Figure 3-24. Scatter-graph for 20-inch pipe at 2.0 percent slope.

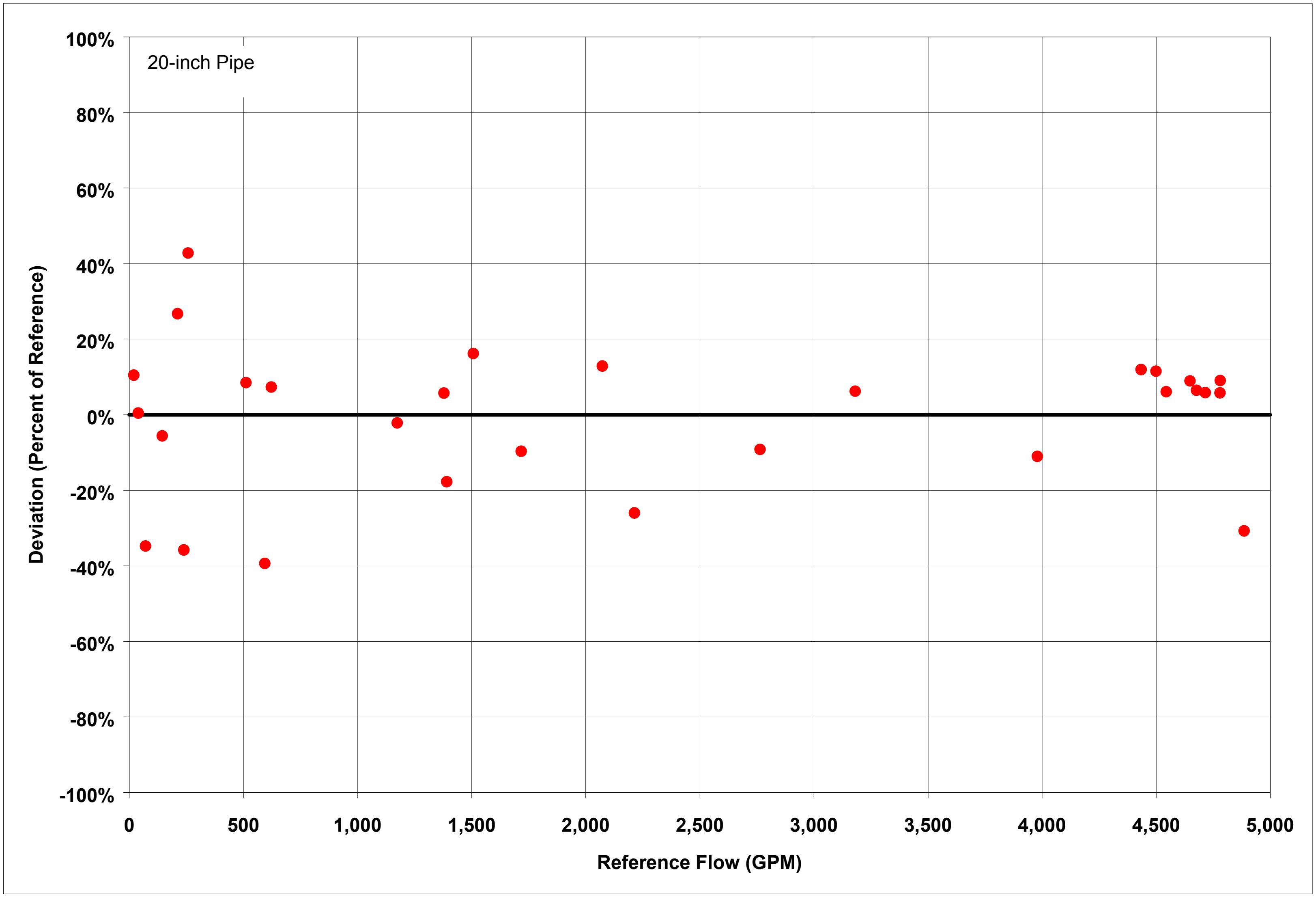


Figure 3-25. Deviation of meter flow to reference flow for 20-inch pipe.

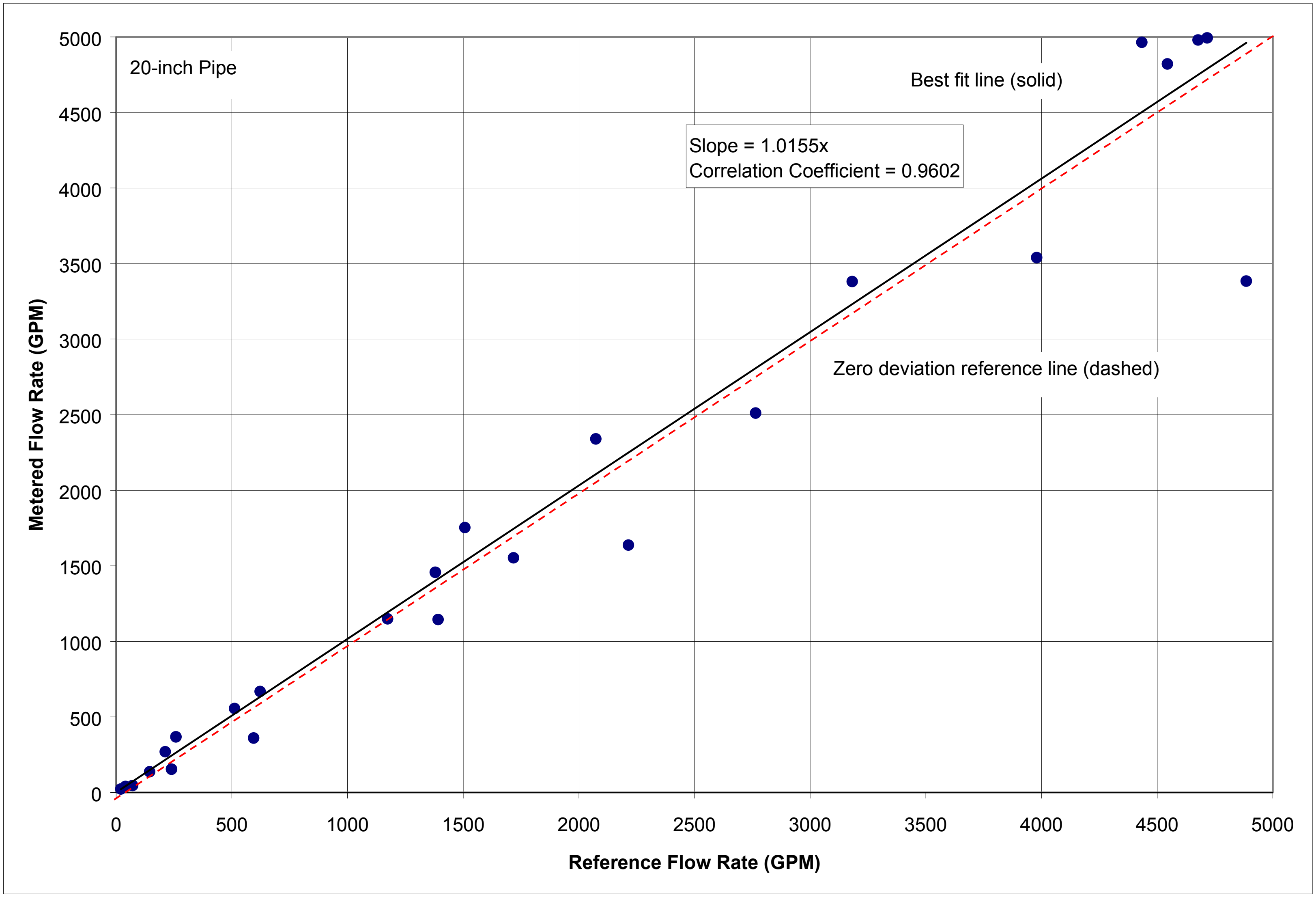


Figure 3-26. Plot of reference flow versus meter flow in 20-inch pipe.

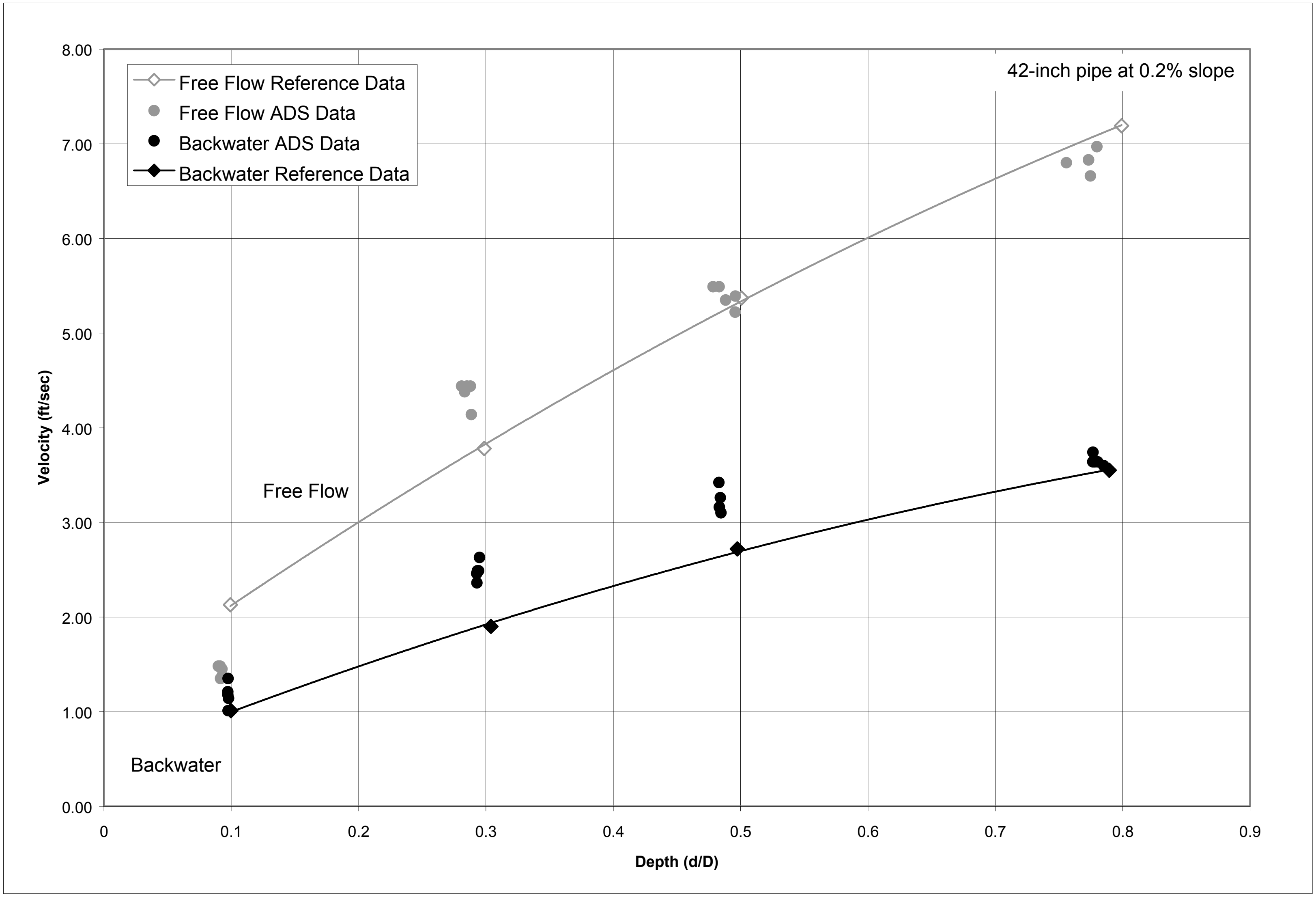


Figure 3-27. Scatter-graph for 42-inch pipe test at 0.2 percent slope.

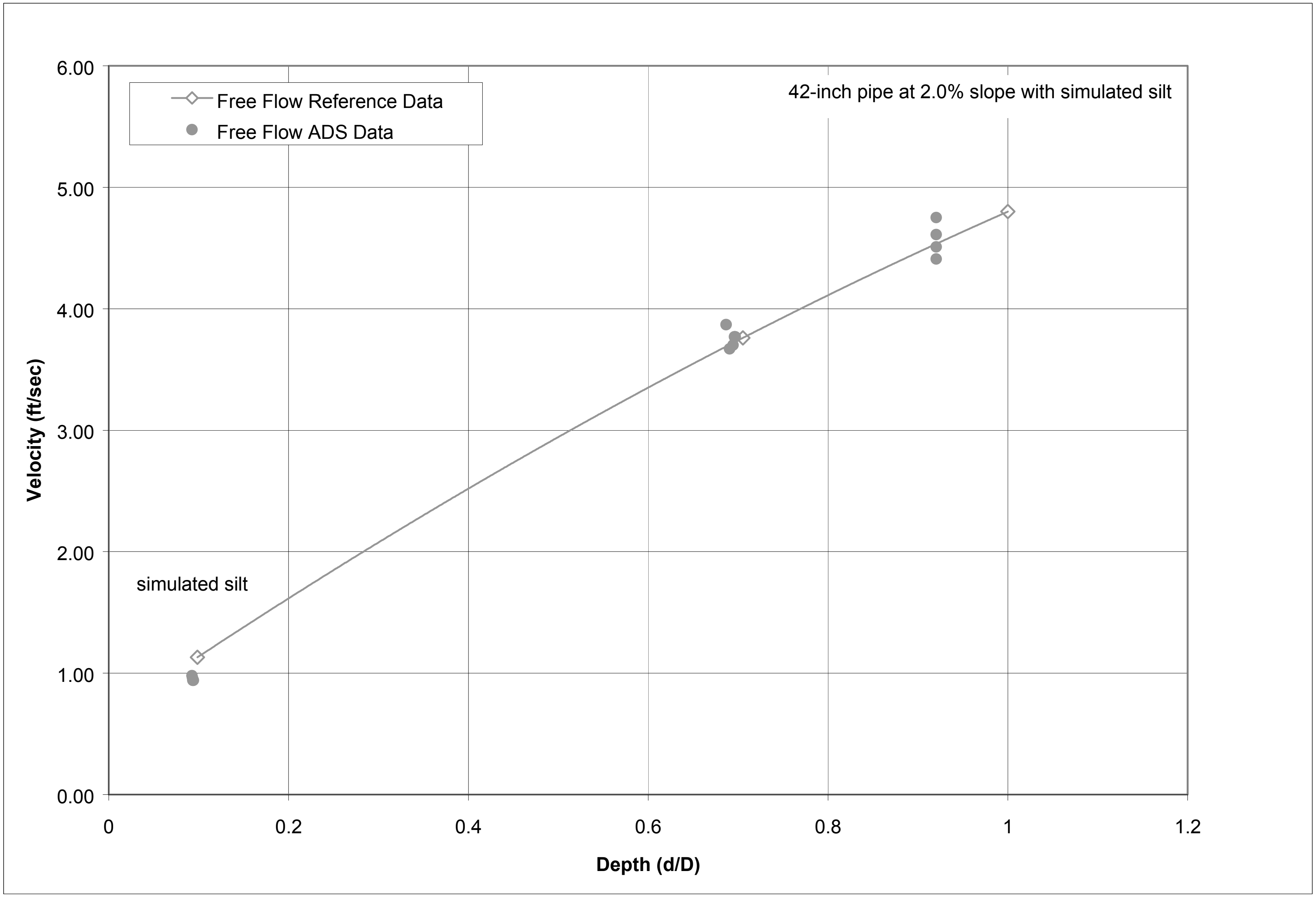


Figure 3-28. Scatter-graph for 42-inch pipe test at 0.2 percent slope with silt.

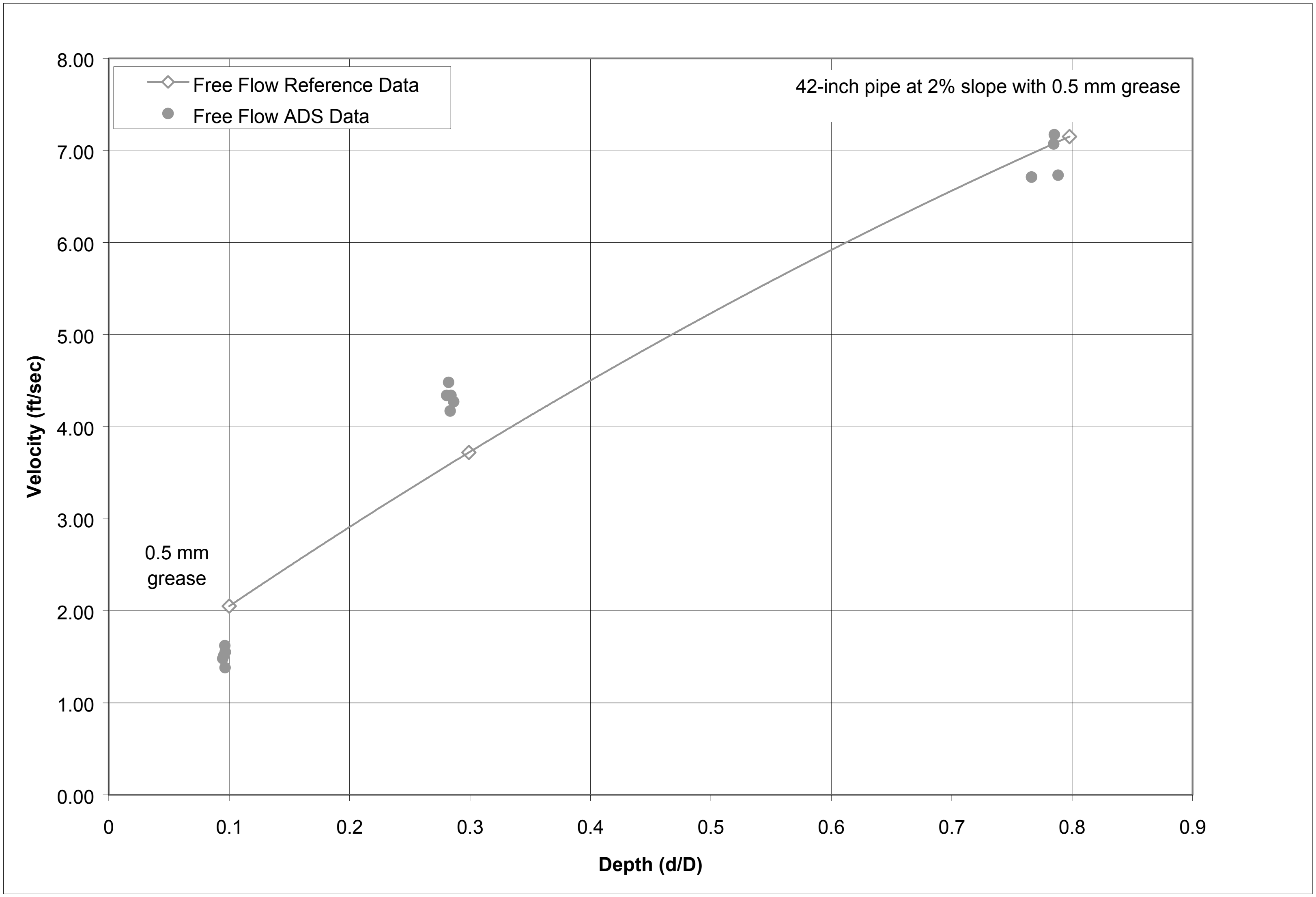


Figure 3-29. Scatter-graph for 42-inch pipe test at 0.2 percent slope with 0.5 mm grease.

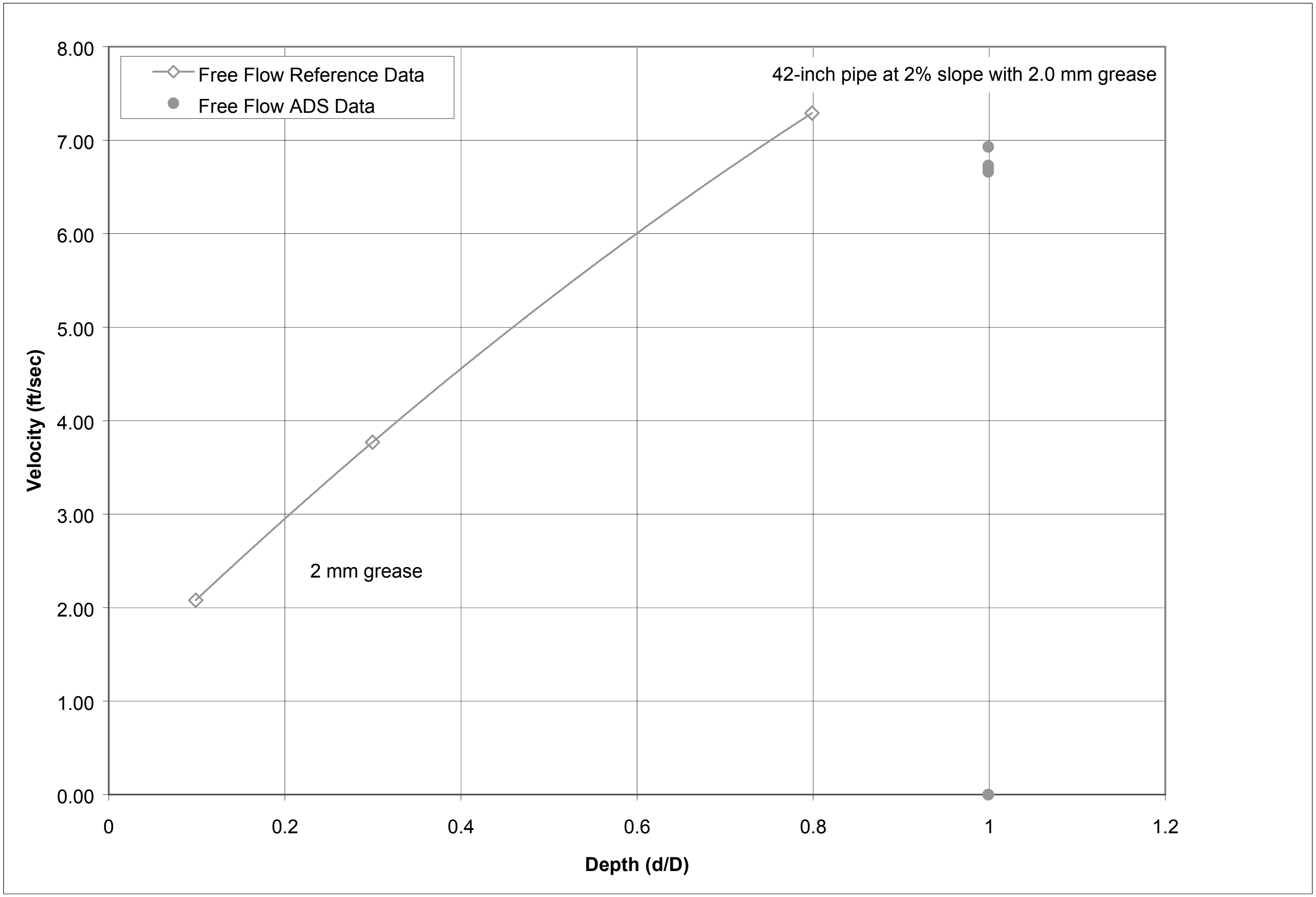


Figure 3-30. Scatter-graph for 42-inch pipe test at 0.2 percent slope with 2.0 mm grease.

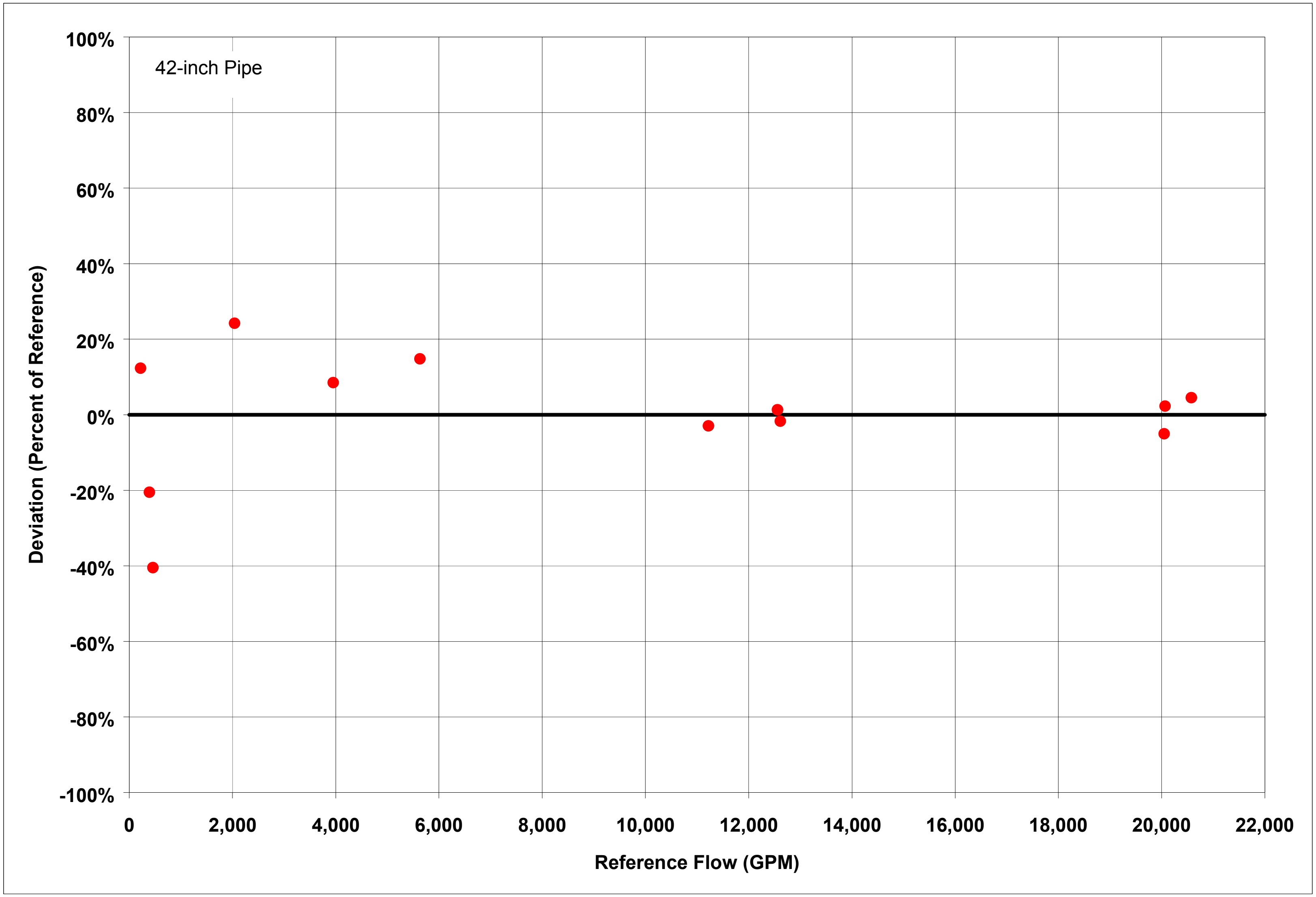


Figure 3-31. Deviation of meter flow to reference flow for 42-inch pipe.

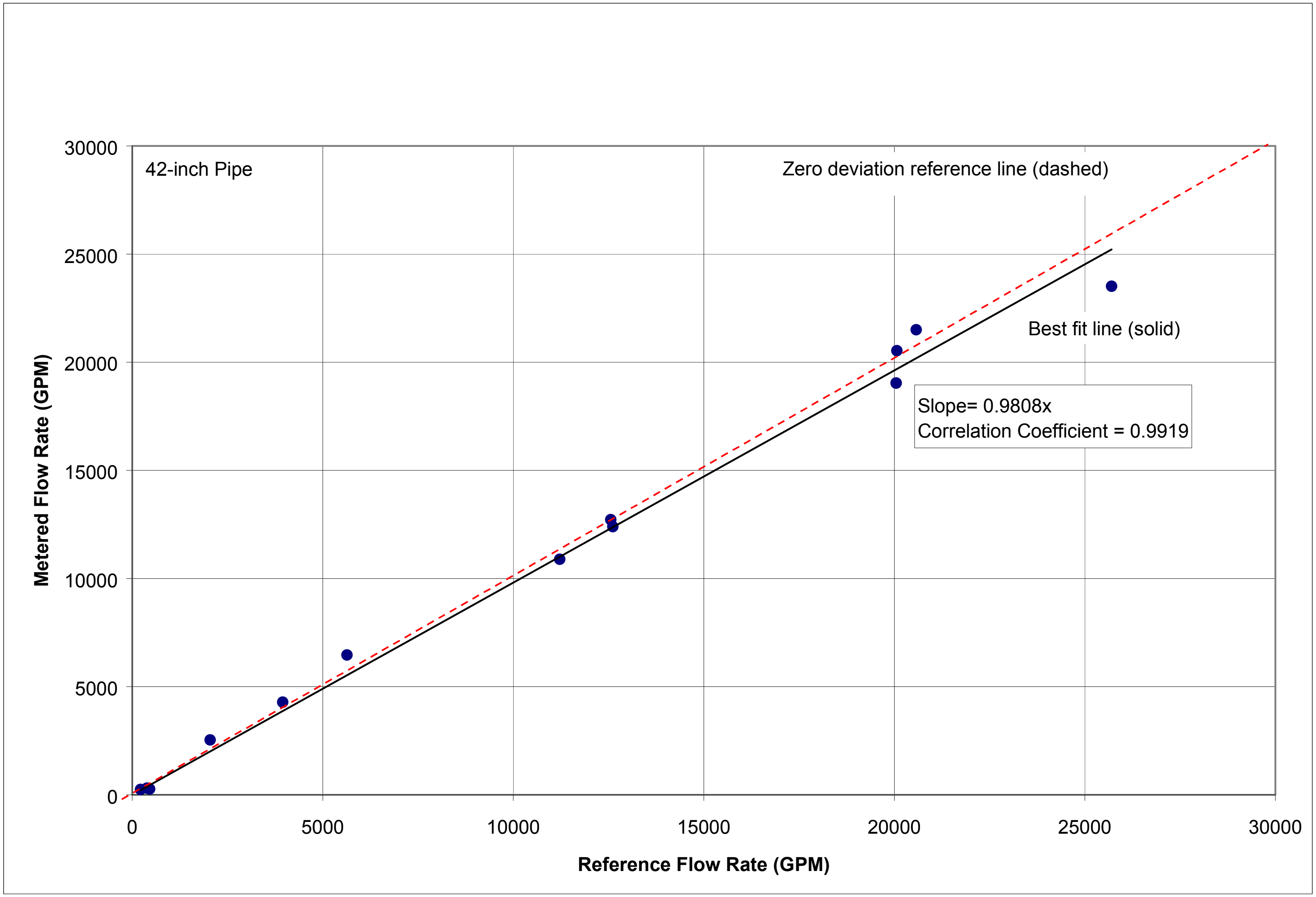


Figure 3-32. Plot of reference flow versus meter flow in 42-inch pipe.

Appendices

A Laboratory Equipment Calibrations and Information
B Raw Laboratory Test Notes and Data
C Operational Procedure and Data Logging Method
D Laboratory Test Data

Glossary

Accuracy - a measure of the closeness of an individual measurement or the mean of a number of measurements to the true value and includes random error and systematic error.

Bias - the systematic or persistent distortion of a measurement process that causes errors in one direction.

Commissioning – the installation of the in-drain removal technology and start-up of the technology using test site wastewater.

Comparability – a qualitative term that expresses confidence that two data sets can contribute to a common analysis and interpolation.

Completeness – a qualitative term that expresses confidence that all necessary data have been included.

Precision - a measure of the agreement between replicate measurements of the same property made under similar conditions.

Protocol – a written document that clearly states the objectives, goals, scope, and procedures for the study. A protocol shall be used for reference during vendor participation in the verification testing program.

Quality Assurance Project Plan – a written document that describes the implementation of quality assurance and quality control activities during the life cycle of the project.

Residuals – the waste streams, excluding final effluent, that are retained by or discharged from the technology.

Representativeness - a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point, a process condition, or environmental condition.

Source Water Protection Stakeholder Advisory Group - a group of individuals consisting of any or all of the following: buyers and users of in-drain removal and other technologies, developers and vendors, consulting engineers, the finance and export communities, and permit writers and regulators.

Standard Operating Procedure – a written document containing specific procedures and protocols to ensure that quality assurance requirements are maintained.

Technology Panel - a group of individuals with expertise and knowledge of in-drain treatment technologies.

Testing Organization – an independent organization qualified by the Verification Organization to conduct studies and testing of mercury amalgam removal technologies in accordance with protocols and Test Plans.

Vendor – a business that assembles or sells in-drain treatment equipment.

Verification – to establish evidence on the performance of in-drain treatment technologies under specific conditions, following a predetermined study protocol(s) and test plan(s).

Verification Organization – an organization qualified by EPA to verify environmental technologies and to issue verification statements and verification reports.

Verification Report – a written document containing all raw and analyzed data, all quality assurance/quality control (QA/QC) data sheets, descriptions of all collected data, a detailed description of all procedures and methods used in the verification testing, and all QA/QC results. The test plan(s) shall be included as part of this document.

Verification Statement – a document that summarizes the Verification Report reviewed and approved and signed by EPA and NSF.

Verification Test Plan – a written document prepared to describe the procedures for conducting a test or study according to the verification protocol requirements for the application of in-drain treatment technology. At a minimum, the test plan shall include detailed instructions for sample and data collection, sample handling and preservation, precision, accuracy, goals, and QA/QC requirements relevant to the technology and application.