# Section 5
# Hydraulic Model Roughness Factor Assignment and Model Calibration

# SECTION 5 – HYDRAULIC MODEL ROUGHNESS FACTOR ASSIGNMENT AND MODEL CALIBRATION

Section 4 allocated average dry weather flow (ADWF) to the VVWRA Interceptor Hydraulic Model, as the first step in the calibration process. This section assigns current friction factors to the Interceptor and to finalize calibration of the Model.

The VVWRA Interceptor Model was first developed in 2005 as a part of the *VVWRA Interceptor Facilities Plan*. The Model was constructed from the design drawings for each Interceptor reach. As-built drawings were used whenever available. Loading manholes were assigned in the Model to match the major lateral connections from member agencies. The ADWF and diurnal patterns at each loading manhole were input from quarterly flow monitoring conducted for VVWRA by private companies in 2003, 2004 and 2005.

For the 2005 Model, Manning's friction factor "N" values were assigned in accordance with industry standards at 0.013. Average flow in the Service Area was approximately 12.0 mgd at the time the 2005 Model was constructed, and had increased at a yearly average rate of over 8% in the three prior years.

The original 2005 Model predicted that several portions of the Interceptor were in a surcharged condition and would be vulnerable to overflow, especially if the high growth rate in the Service Area continued. These surcharged areas were: at the reach through and immediately downstream from the Upper Narrows; immediately upstream from the Lower Narrows; and immediately downstream from the Lower Narrows.

VVWRA was contemplating construction of regional water reclamation plants at that time. Construction to increase Interceptor capacity would be expensive and necessitate environmental mitigation measures, special permits and easement acquisition.

A field investigation was initiated in 2007 to determine if actual flow depths in the reaches that the Model predicted to be surcharged matched Model levels. The Upper

Narrows and immediately upstream from the Lower Narrows were inspected. The inspection was conducted on a weekend under conditions of peak dry weather flow. Both areas showed flow depths that were considerably lower than those predicted by the 2005 Model

The 2005 Model used a total system flow (at the output point) that was well documented by the quarterly monitoring at the major connection points to the Interceptor and the Influent Flow Meter at the RWWRF. Therefore, the discrepancy between 2005 Model output and actual observed conditions had to come from any one of or a combination of three factors:

1. The assumed proportion of total system flow to the Model load manholes and the diurnal pattern of that flow were incorrect.
2. Manning's "N" values were different than the constant 0.013 used in the 2005 Model.
3. The sewer slopes shown on the design drawings were different than the actual existing slopes.

A Model calibration procedure was developed to better estimate actual physical conditions in the Interceptor. The calibration procedures were designed to facilitate the answer to the question of: What, if any, improvements are required in the Interceptor prior to the activation of regional water reclamation plant(s)?

Temporary flow monitoring was conducted to establish Manning's "N" assumptions. Flow monitors were placed to represent the various slopes and pipe materials in the VVWRA Interceptor.

An electronic field survey was conducted at all accessible manholes to establish inverts and sewer lengths for input to the model for calculation of slope. Section 2 describes the method used and resultant data.

The *2007 Facilities Plan Amendment* applied this calibration method to the Interceptor over the reaches from the Upper Narrows to the RWWRF. This SMP applies the calibration method to the Interceptor reaches upstream from the Upper Narrows to generate a complete calibrated Interceptor Model.

## 5.1 INTERCEPTOR MODEL SOFTWARE

$H_2OMAP$ Sewer (Version 9.0) produced by MWH Soft, Inc. was the software used to develop and execute the VVWRA Interceptor Model. $H_2OMAP$ Sewer is a stand-alone GIS-based computer program for use in the modeling and analysis of sewer collection systems. The program effectively and accurately models both dry-weather and wet-weather flows based on a variety of user inputs. The model uses advanced calculations to predict dynamic flow conditions within the sewer system. This includes the use of Manning's equation for prediction of water level as well as dynamic calculations to predict hydraulic grade lines impacted from downstream flow conditions.

## 5.2 FRICTION FACTOR CALIBRATION

The Interceptor Model utilizes Manning's Equation for calculation of results. Manning's equation is calculated as follows:

$$Q = 1.49/n*A*R^{2/3}*s^{1/2}$$

where

$Q$ = flow, cfs

$n$ = Manning's friction factor

$A$ = Flow Area, $ft^2$

$R$ = Hydraulic Radius, ft

$s$ = slope of pipe, ft/ft

The existing facilities assessment described in Section 2 provided accurate invert elevations at all accessible sewer manholes; thereby satisfying "s" in the above equation. Pipe sizes were also verified in the assessment of existing facilities; thereby facilitating the calculation of "A" and "R". The flow metering described in Section 3 measures depth and velocity; thereby yielding "A" and "R" when combined with pipe diameter.

With four of the five variables from Manning's equation verified in the field from the survey and flow monitoring efforts, the only remaining variable for model calibration is Manning's friction factor "N". Typical "N" values used for pipeline design vary based on pipe materials as shown in Table 5-1.

**Table 5-1**
**Typical Mannings "N" Values**

| Pipe Material | Typical Manning's "N" Value |
|---|---|
| Plastic (PVC) | 0.009 |
| Vitrified Clay | 0.013 to 0.015 |
| Ductile Iron | 0.013 to 0.015 |
| Concrete | 0.012 to 0.014 |
| Typical "N" Values from *Civil Engineering Reference Manual 10th Edition*, Michael R. Lindeburg | |

The values above are those typically used in a design application. Under laboratory conditions using clean water, "N" has been measured as low as 0.006.

### 5.2.1 Hesperia Friction Factor Calibration

Manning "N" values were estimated from the flow monitoring conducted for this SMP. Flow meters were placed in December 2007 and January 2008 to capture a variety of slopes in the Hesperia Interceptor. Table 5-2 shows the calculated "N" values from flow monitoring data at the three Hesperia sites.

**Table 5-2**
**Hesperia Calculated "N" vs Slope from Monitoring**

| Interceptor Reach | Pipe No. | Pipe Slope, ft/ft | Calculated "N" |
|---|---|---|---|
| Hesperia | 45 | 0.0019 | 0.006 |
| | 55 | 0.0005 | 0.008 |
| | 70 | 0.0134 | 0.010 |

Flow monitoring data and diurnal variations were assessed to establish Model "N" values for the ranges of slope in the Hesperia Interceptor. Manning's "N" values were selected to provide a 5%-10% factor of conservatism at peak flow conditions. These "N" value assumptions are shown in Table 5-3.

**Table 5-3**
**Hesperia Model "N" Assumptions**

| Interceptor Reach | Pipe Slope Range | Selected "N" |
|---|---|---|
| **Hesperia** | <0.001 | 0.065 |
| | 0.001 < 0.002 | 0.0105 |
| | 0.002 < 0.004 | 0.0115 |
| | >0.004 | 0.0136 |

Friction factor ("N") assumptions were loaded into the Model per Table 5-3, above. Average flow and diurnal patterns were input to loading manholes, as described in Section 3. The Interceptor Model was run to compare Model output versus flow monitoring data. The weekend flow pattern was selected. The results for Model versus monitored d/D values for weekend flows are shown in Figures 5-1 through 5-3. The results show a close correlation between the Model output and field measured conditions.

**Figure 5-1**
**Hesperia MH 45**
**Monitored vs. Modeled Weekend Percent Full (d/D)**
**(18" Pipe)**

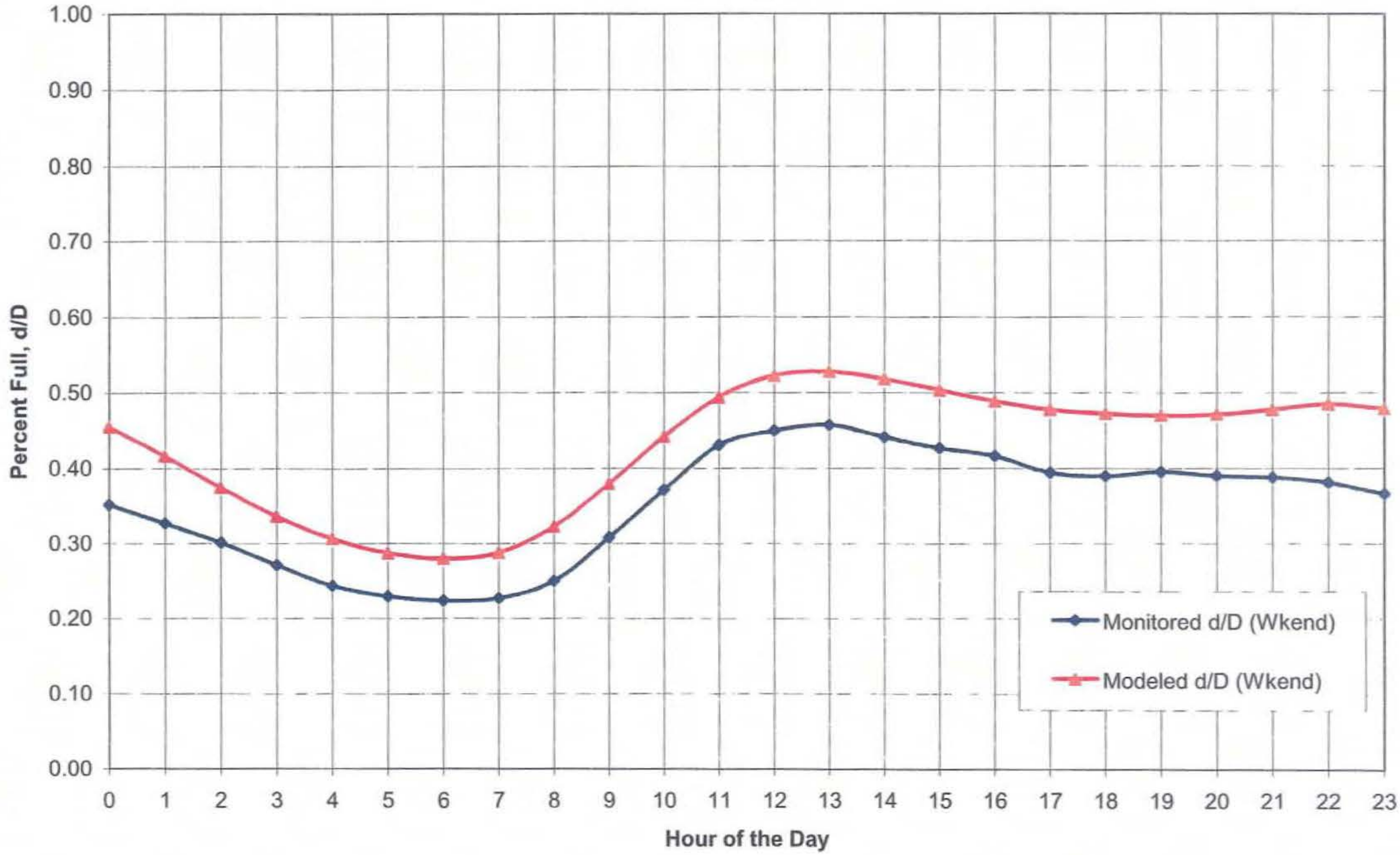


**Figure 5-2**
**Hesperia MH 55**
**Monitored vs. Modeled Weekend Percent Full (d/D)**
**(18" Pipe)**

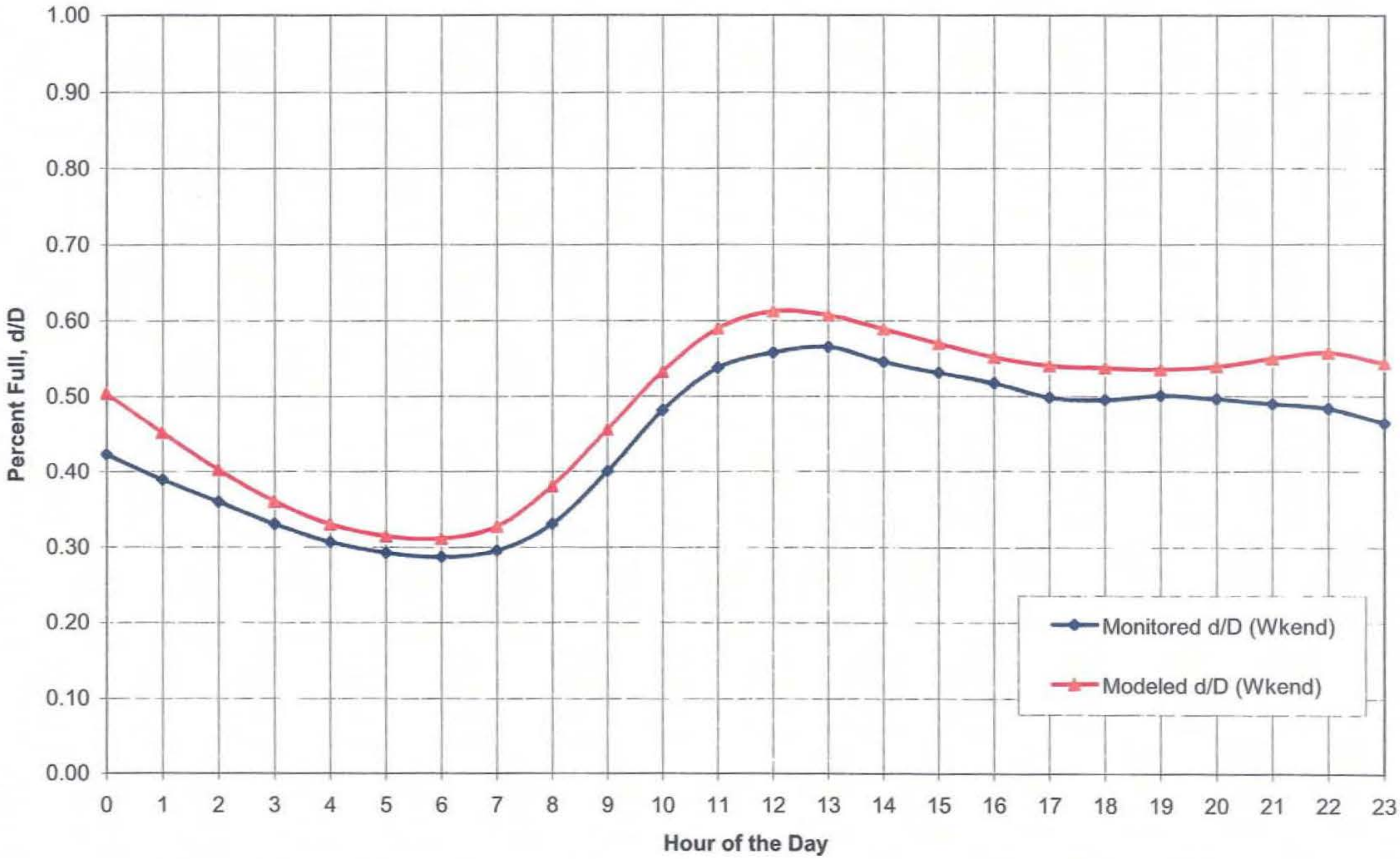
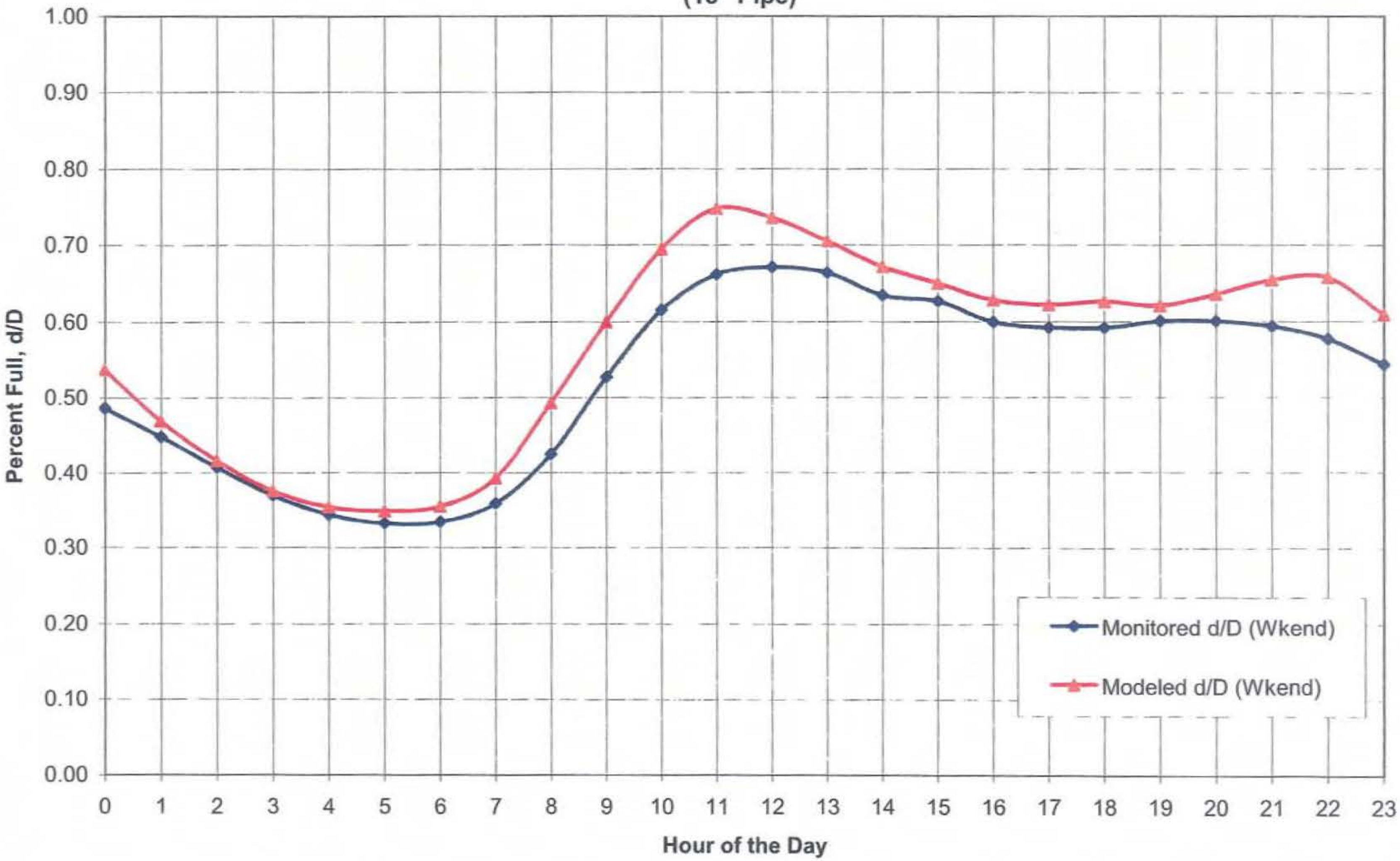


**Figure 5-3**
**Hesperia MH 70**
**Monitored vs. Modeled Weekend Percent Full (d/D)**
**(15" Pipe)**



### 5.2.2 Spring Valley Lake/CSA 64 Model Calibration

Three major points of loading were input to the Model for the Spring Valley Lake Interceptor: Spring Valley Lake, VSD-2 and the State Park. The derivation and resultant flow allocations and diurnal patterns for the load points tributary to this reach are described in Section 4.

Manning "N" values were estimated from the flow monitoring conducted for this SMP. Flow meters were placed in March of 2008 to capture a variety of slopes in the Spring Valley Lake Interceptor. Table 5-4 shows the average day calculated variation in "N" values from flow monitoring data at the three sites.

**Table 5-4**
**SVL/CSA-64 Calculated "N" vs Slope from Monitoring**

| Interceptor Reach | Pipe No. | Pipe Slope, ft/ft | Calculated "N" |
|---|---|---|---|
| SVL/CSA-64 | 4 | 0.0042 | 0.019 |
| | 17 | 0.0026 | 0.016 |
| | 22 | 0.0033 | 0.014 |

The flow monitoring data and diurnal variations were assessed to establish Model "N" values in the Model for the ranges of slope along the entire Spring Valley Lake Interceptor. Manning's "N" values were selected to provide a 5%-10% factor of conservatism at peak flow conditions. These "N" value assumptions are shown in Table 5-5.

**Table 5-5**
**SVL/CSA-64 Model "N" Assumptions**

| Interceptor Reach | Pipe Slope Range | Selected "N" |
|---|---|---|
| SVL/CSA-64 | <0.01 | 0.013 |
| | $0.001 \leq 0.004$ | 0.016 |
| | $0.004 < 0.009$ | 0.019 |

With the loading manhole flow and "N" assumptions described above, the Interceptor Model was run to compare Model output versus flow monitoring data. The results for Model versus monitored d/D values for weekend flows are shown in Figures 5-4 through 5-6. Weekend flows were chosen because their average flow is approximately 5%-10% higher at peak hour than weekday flow to provide a factor of safety when Interceptor capacity is tested with the calibrated model. The results show a close correlation between the Model output and field measured conditions.

### 5.2.3 Apple Valley Model Calibration

No current flow monitoring was available for assignment of flow and diurnal patterns to loading points in the South Apple Valley Interceptor. Therefore, flow monitoring under this SMP was conducted in the South Apple Valley Interceptor at eight (8) locations within the Interceptor and in major laterals feeding the interceptor to establish existing flow and diurnal patterns at connection points. Section 4 provided the loadings and diurnal flow patterns from this effort.

In addition to flow monitoring, an assessment of the Riverside Pump Station 2 was conducted. The Riverside 2 pump station lifts sewage from a residential section of South Apple Valley (SAV). The lift station force main discharges into the VVWRA South Apple Valley Interceptor at SAV Manhole #4, near the end of the Interceptor behind the Lewis Learning Center. Figure 5-7 shows the force main lateral connection to the SAV Interceptor. The pump station assessment included:

1. A physical inspection of the station.
2. A briefing from Town Staff on station control.
3. A measurement of sewer flow depth versus pumps in operation.
4. Review of the pump curves.

**Figure 5-4**
**Spring Valley Lake MH 22**
**Monitored vs. Modeled Weekend Percent Full (d/D)**
**(21" Pipe)**

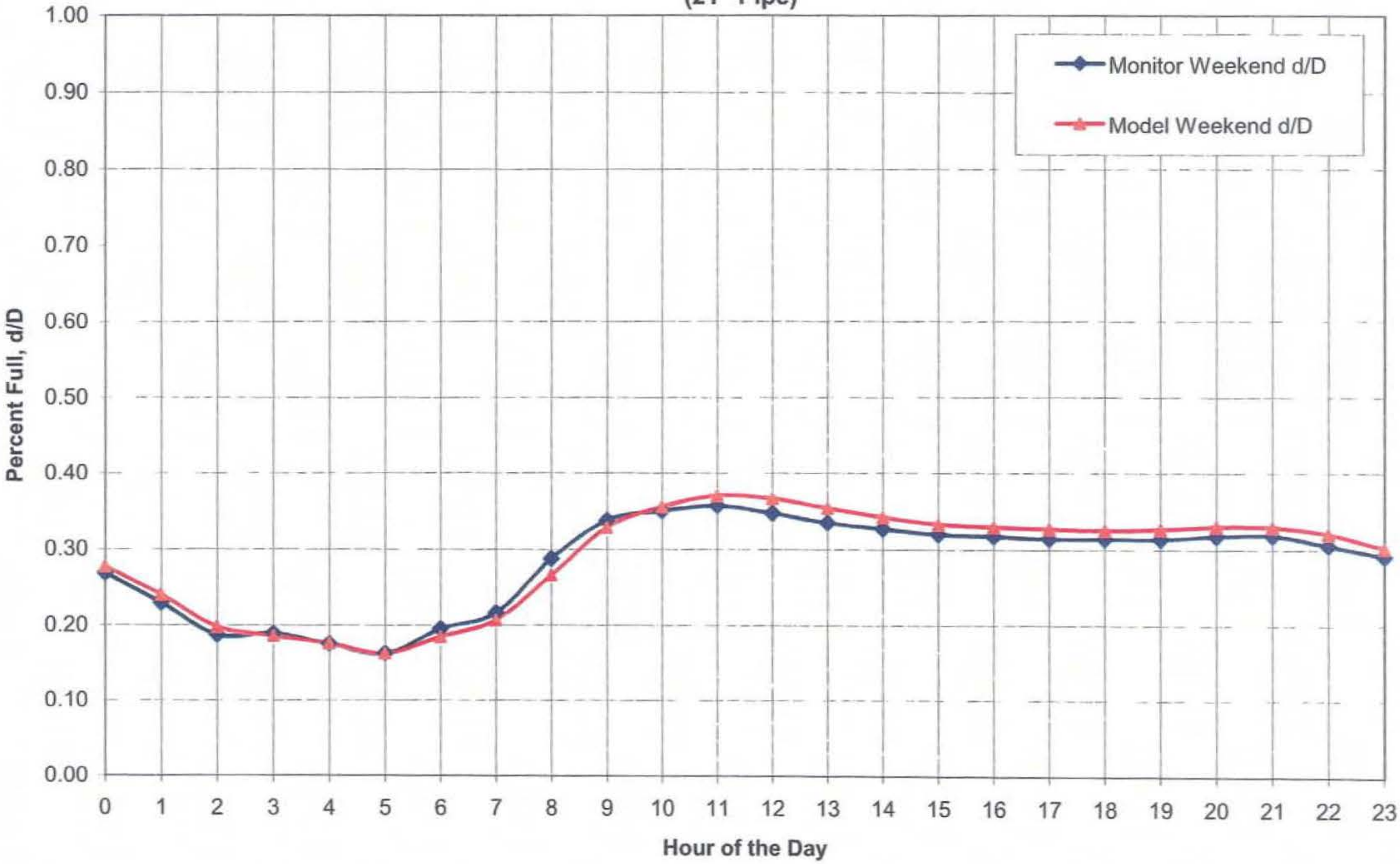


**Figure 5-5**
**Spring Valley Lake MH 17**
**Monitored vs. Modeled Weekend Percent Full (d/D)**
**(21" Pipe)**

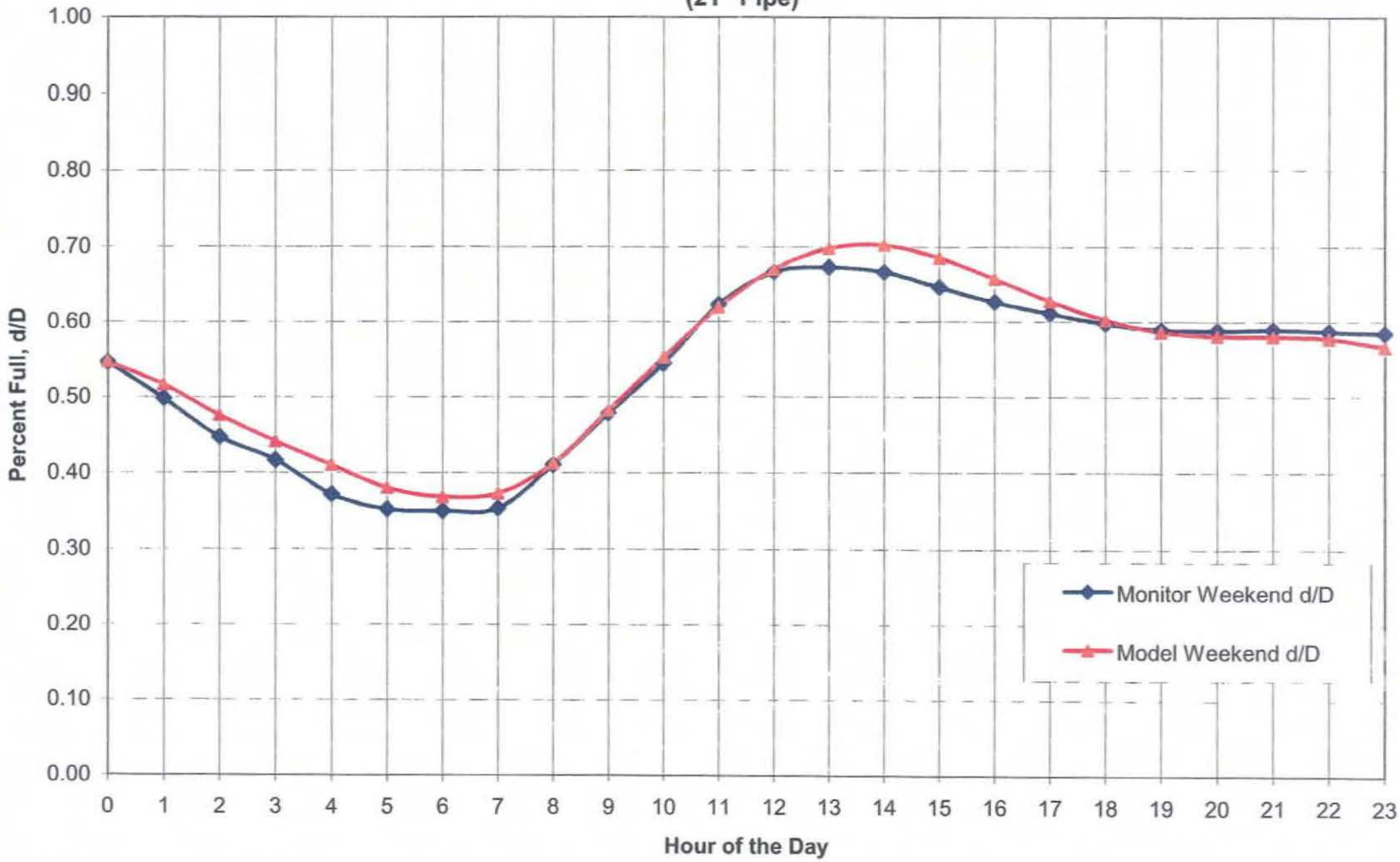


**Figure 5-6**
**Spring Valley Lake MH 04**
**Monitored vs. Modeled Weekend Percent Full (d/D)**
**(27" Pipe)**

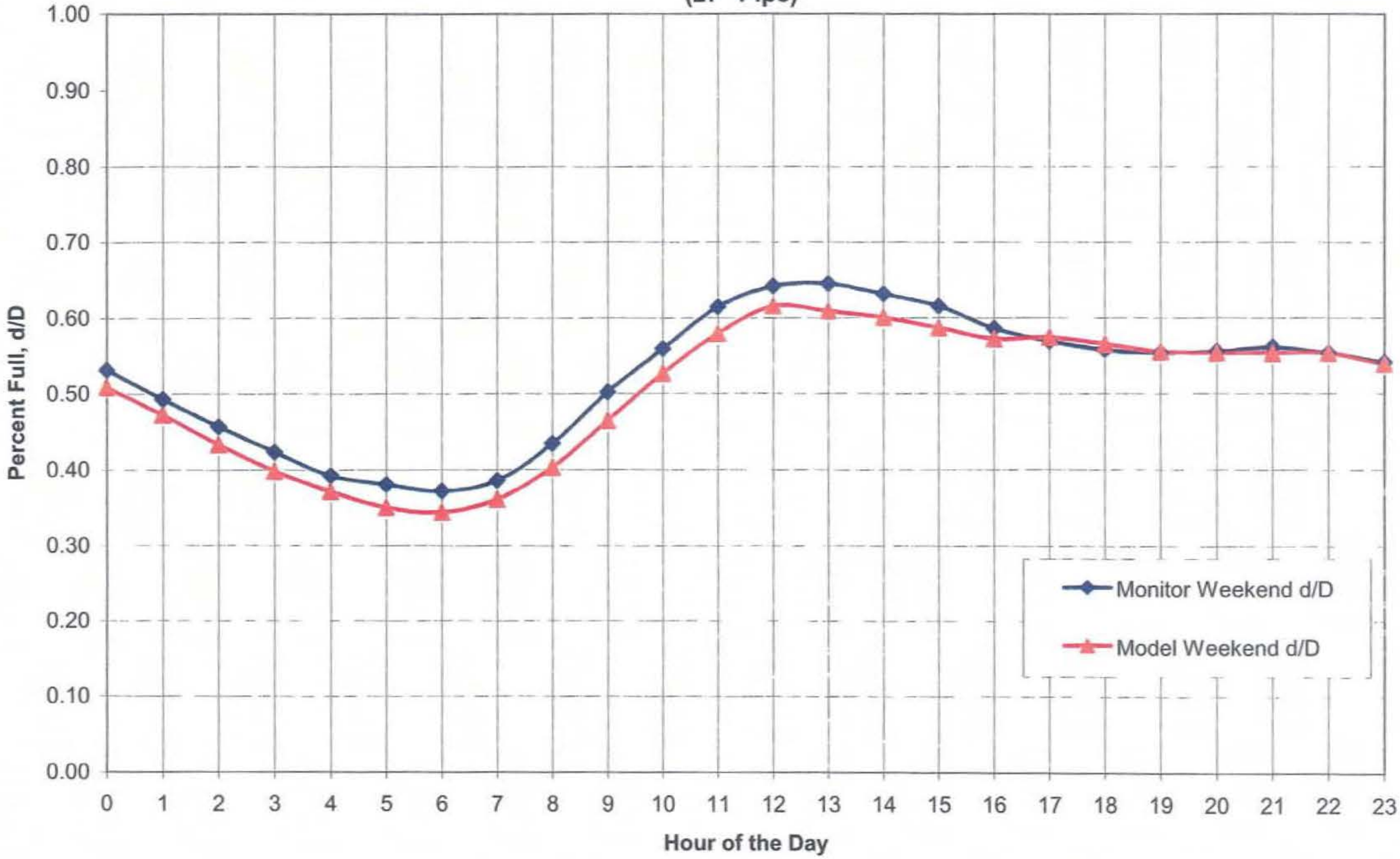


**Figure 5-7**
**Apple Valley Riverside Pump Station Force Main Connection**


A peak flow of 3 cfs was assigned to the Riverside Pump Station loading manhole based on review of the pump curve and flow monitoring data.

Manning "N" values were estimated from the flow monitoring conducted for this SMP. Flow meters were placed in March 2008 to capture a variety of slopes in the South Apple Valley Interceptor. Table 5-6 shows the average calculated variation in "N" values from flow monitoring data.

**Table 5-6**
**South Apple Valley Calculated "N" vs Slope from Monitoring**

| Interceptor Reach | Pipe No. | Pipe Slope, ft/ft | Calculated "N" |
|---|---|---|---|
| South Apple Valley | 2 (DIP) | 0.0110 | 0.0150 |
| | 17 | 0.0057 | 0.0125 |
| | 43 | 0.0134 | 0.0110 |
| | 68 | 0.0025 | 0.0120 |

The flow monitoring data and diurnal variations were assessed to establish Model "N" values for the ranges of slope in the Spring Valley Lake Interceptor. Manning's "N" values were selected to provide a 10% factor of conservatism at peak flow conditions. These "N" value assumptions are shown in Table 5-7.

**Table 5-7**
**South Apple Valley Model "N" Assumptions**

| Interceptor Reach | Pipe Slope Range | Selected "N" |
|---|---|---|
| **South Apple Valley** | <0.002 | 0.0121 |
| | 0.0020 ≤ 0.0030 | 0.0132 |
| | 0.0030 ≤ 0.0046 | 0.0154 |
| | 0.0046 ≤ 0.0100 | 0.0143 |
| | 0.0100 ≤ 0.0134 | 0.0121 |
| | 0.0134 ≤ 0.0200 | 0.0110 |
| | >0.0020 | 0.0990 |
| | DI Pipe | 0.0165 |

These "N" values were input in the model and run under existing conditions. The diurnal patterns were developed based on this flow monitoring for the loading points along the South Apple Valley Interceptor.

The results for model versus monitored d/D values at the monitored manholes for weekend average flows are shown in Figures 5-8 through 5-11. The results show a close correlation between the model and field measured conditions.

**Figure 5-9**
**South Apple Valley MH 43**
**Monitored vs. Modeled Weekend Percent Full (d/D)**
**(12" Pipe)**

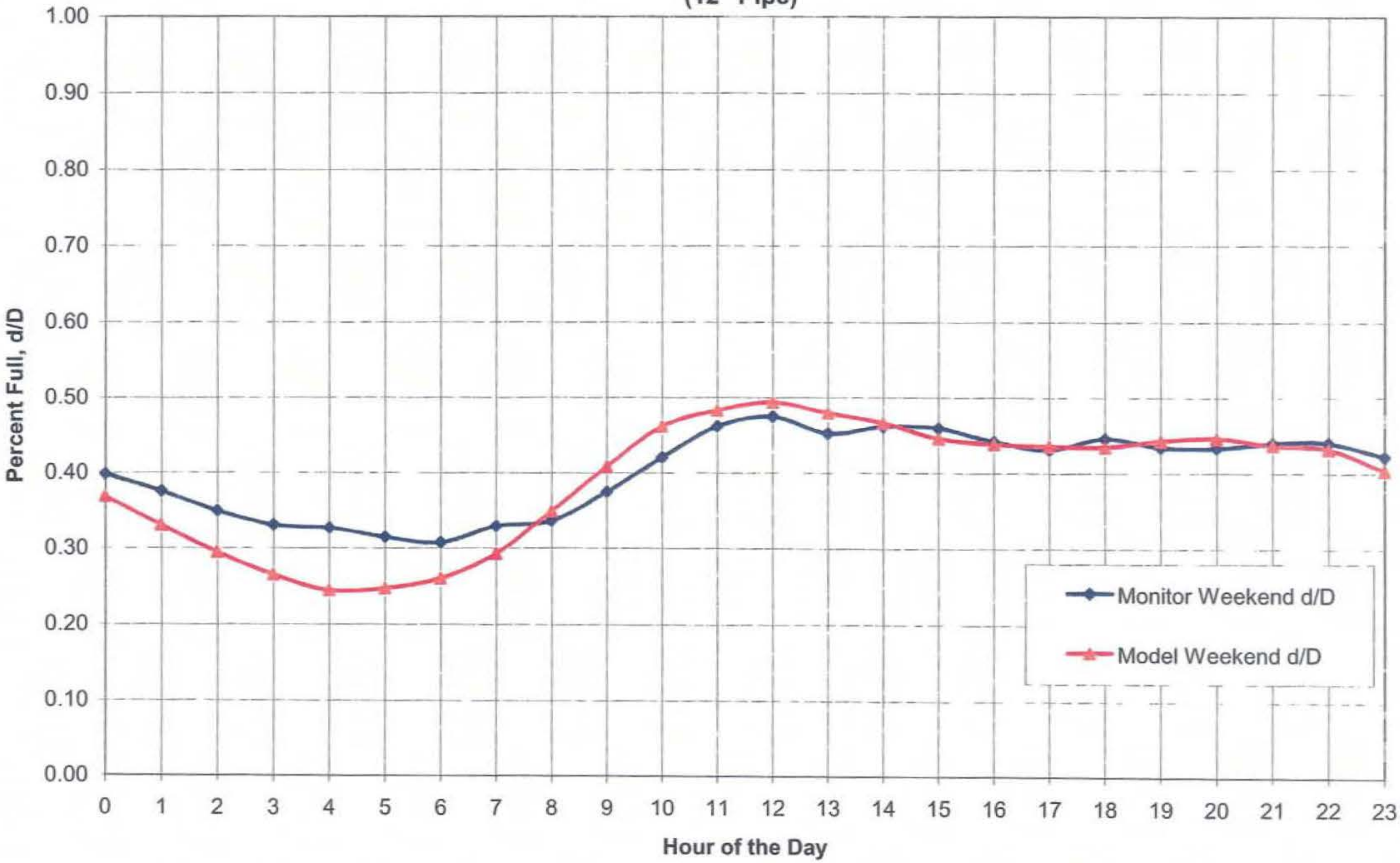
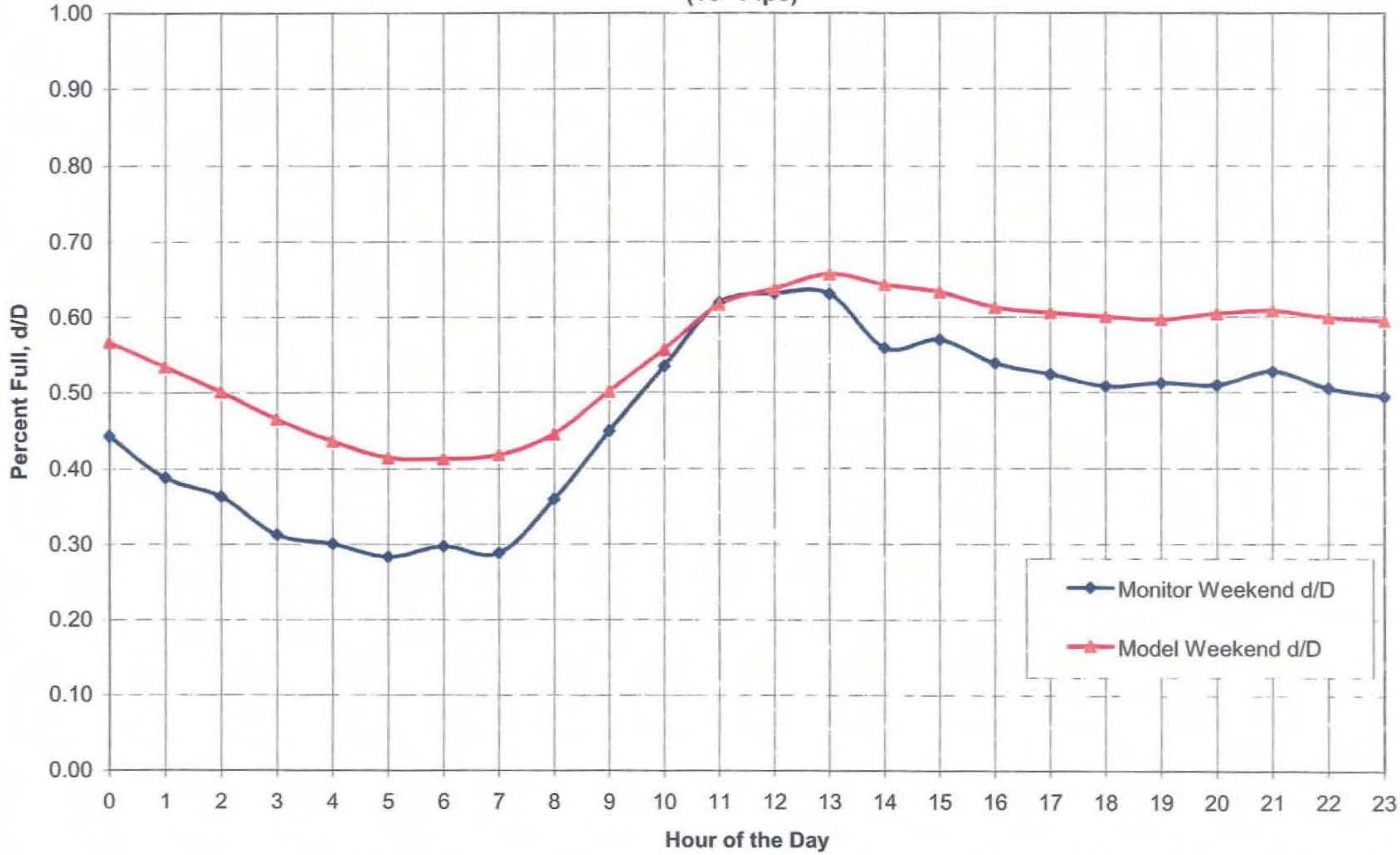


**Figure 5-11**
**South Apple Valley MH 02**
**Monitored vs. Modeled Weekend Percent Full (d/D)**
**(16" Pipe)**



### 5.2.4 Victorville Model Calibration

Extensive flow monitoring was conducted in the Victorville Interceptor in support of the *2007 Interceptor Facilities Plan Amendment*. The model was calibrated for these sections of pipe based on the data from this monitoring. It was found during the analysis that the Vitrified Clay Pipe (VCP) sections of the Victorville Interceptor, in particular, those with the flattest slopes exhibited the lowest "N" values while the steeper sloped VCP pipes were slightly higher. All concrete pipelines, (Schedules 1 and 2 and Schedules 1 and 2 Relief) monitored for support of the 2007 Facilities Plan Update, calibrated to an "N" of approximately 0.013.

The calculated "N" values were evaluated against the pipe slope. The following representative "N" values in Table 5-8 were used in the calibrated model for the following pipe slope ranges in the Victorville Interceptors:

**Table 5-8**
**Victorville Model "N" Assumptions**

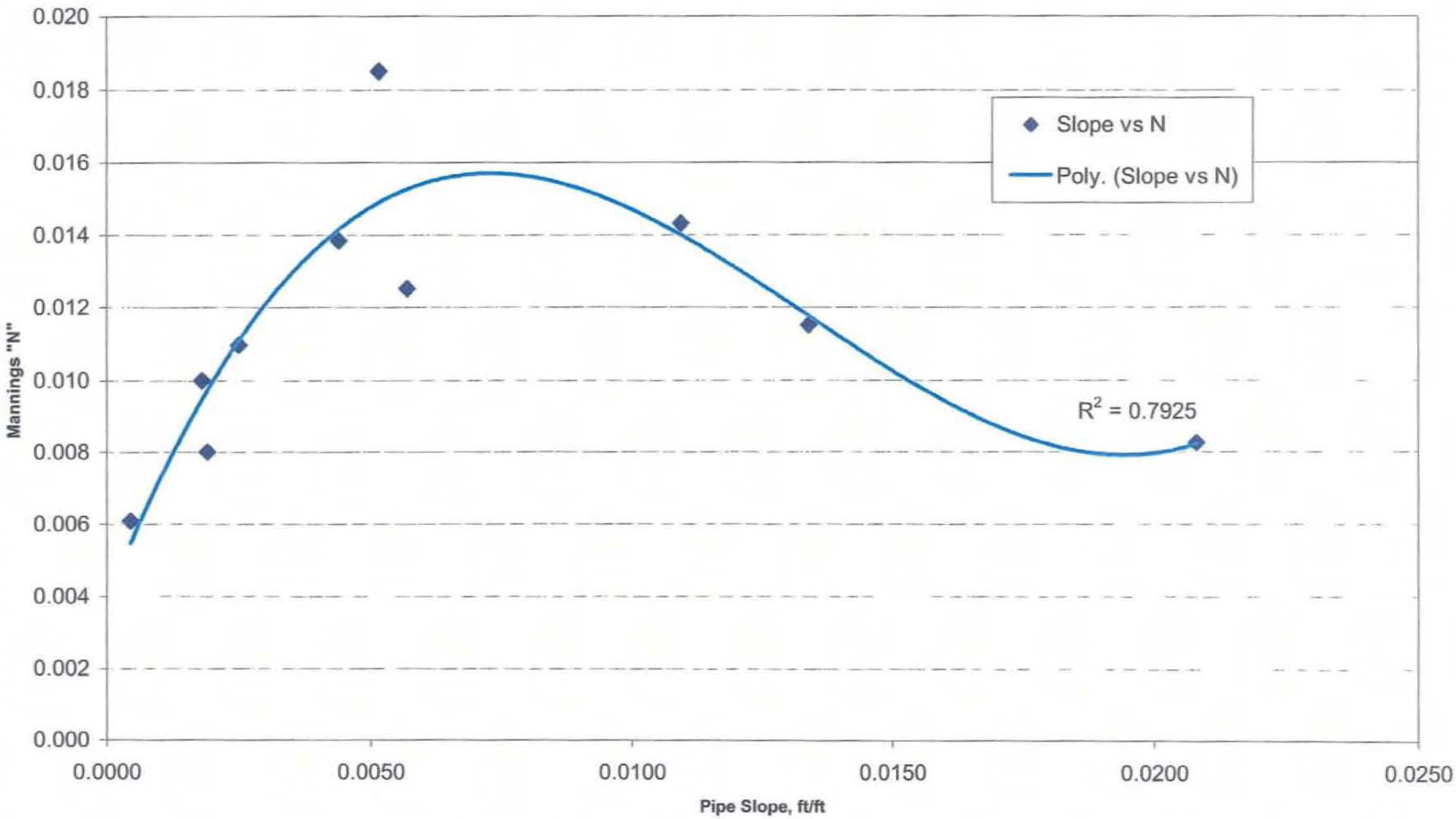
| Interceptor Reach | Pipe Slope Range | Selected "N" |
|---|---|---|
| Victorville | <0.01 | 0.0080 |
| | 0.001 ≤ 0.003 | 0.0090 |
| | >0.003 | 0.0110 |
| | Concrete Pipe | 0.0130 |

### 5.2.5 Manning's "N" Investigation

Manning's Formula "N" values were derived from the flow monitoring conducted for this SMP and the monitoring conducted for the September 2007 *Interceptor System Facilities Plan Amendment.* The "N" values included concrete, VCP and PVC pipe from 10 inches in diameter to 42 inches in diameter. These "N" values versus pipe slope are graphed on Figure 5-12.

A best-fit line has been shown on the graph. The best-fit line generally shows a bell curve with the lowest "N" values at each end of the curve and the highest values in the middle. There could be several reasons for this observation:

**Figure 5-12**
**Pipe Slope vs Mannings "N"**



1. Flow is laminar at very low and very high slopes, yielding the lowest friction factors.
2. The very shallow slopes cause low velocities that, in turn, cause grease and oils to fall out of solution and coat the pipe; thereby minimizing the friction factor.

The customization of "N" is not recommended for standard practice in sizing sewer systems. Appropriate levels of conservatism should be considered when designing a new or rehabilitated system that is expected to be in service for many years. In addition, no long term studies are available that document the consistency of "N" over long periods of time.

The customization was undertaken for this SMP because very near term decisions must be made regarding building regional water reclamation facilities versus upgrading the Interceptor. Therefore, a very fine tuned "N" was required to determine if the Interceptor could be operated without overflow while the regional water reclamation plants are constructed.

### 5.2.6 Overall Demonstration of Model Calibration

The friction factor calibration procedures and good correlation results for individual sections of the VVWRA Interceptor are described above. A final test of Interceptor Model calibration was conducted to verify authenticity. This test used the average yearly flow in 2008, proportioned this flow over the loading manholes in accordance with the estimations included in Section 3 and compared Model output at the RWWRF to the diurnal flow pattern registered at the RWWRF's Influent Flow Meter for the period of January to February 2008.

The results of this comparison are shown in Figure 5-13. The figure shows the overall pattern of flow at the plant is similar in both the model and as registered at the plant influent flow meter. A slightly higher peak flow is generated in the Model which provides a level of conservatism in flow and pipe full levels when testing Interceptor capacity. A higher minimum flow is predicted in the Model as well, which has no impact on capacity analysis as peak flows will always provide greater flow depths in the Interceptor.

**Figure 5-13**
**RWWRF Influent Flow Meter vs Model Flow at RWWRF**