Sacramento Regional County Sanitation District

Interceptor Sequencing Study

Technical Memorandum 2
Design and Performance Storms and Approach for Modeling Spatial Rainfall Variation

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Sacramento Regional County Sanitation District

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TECHNICAL MEMORANDUM
NO. 2
Design and Performance Storms Approach For Modeling Spatial Rainfall Variation

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DESIGN AND PERFORMANCE STORMS AND APPROACH FOR MODELING SPATIAL RAINFALL VARIATION

1.0 INTRODUCTION

This TM documents the findings of Subtask 2.4 (Develop Design and Performance Storms) and Subtask 2.5 (Develop Approach for Modeling Spatial Rainfall Variation) of the SRCSD Interceptor Sequencing Study.

The objective of Subtask 2.4 is to identify potential alternative design and performance storms that can be used, along with other design flow criteria, to assess the capacity of the SRCSD interceptors, evaluate the timing of need for additional capacity, and develop alternative improvement projects to relieve the existing system and to serve future development. By definition, performance storms are storms used to determine if the system has adequate capacity, and are sometimes called “trigger” storms because they are used to trigger improvement projects. Design storms are used to size the improvements. Design storms are larger than performance storms, since it is generally cost-effective to provide a somewhat higher level of service in an improvement project once it has been triggered.

The objective of Subtask 2.5 is to determine an appropriate approach for modeling design and performance storms that realistically reflects the spatial variation in rainfall over the SRCSD service area.

This TM is divided into the following sections:

1. Introduction
2. Continuous Simulation Methodology
3. Continuous Simulation Model Calibration
4. Design and Performance Storms
5. Rainfall Spatial Variation
6. Storm Movement

2.0 CONTINUOUS SIMULATION METHODOLOGY

Continuous simulation modeling was the primary analytical tool used to identify candidate storms. In brief, a continuous simulation model computes wastewater flows including infiltration/inflow (I/I) resulting from a long period of historical hourly rainfall data, and then ranks the historical storm peak flows to estimate their probability of occurrence in any given year (i.e., return period). Based on these probabilities, it is possible to select historical

storms as design and performance storms that provide the desired level of protection against sewer overflows.

The alternative to selecting historical storms as design and performance storms through continuous simulation is to use rainfall statistics to create synthetic storms. That is the approach that many stormwater and wastewater agencies use, and is the approach that was used for SASD's Master Plan and in past SRCSD studies. One commonly-used synthetic storm approach consists of assembling a storm that combines the critical rainfall intensities corresponding to the desired return period for each time period in the storm. In other words, a synthetic 10-year storm includes the 10-year one-hour rainfall intensity, as well as the 10-year two-hour intensity, the 10-year three-hour intensity, and so on for the duration of the storm. These synthetic storms are considered to be conservative, since they have high intensities matching the return period for all intermediate time periods during the storm. Synthetic storms of this type could be expected to occur less frequently than suggested by the return period of the individual rainfall intensities that make them up.

When applied to wastewater systems (as opposed to storm drainage systems), other factors come into play that can add to the difficulty of estimating the true return period of peak flows generated using a synthetic storm approach. These factors include the duration of the storm (what is the critical duration that will produce the highest peak flows?), timing of the storm during the day (does the peak I/I coincide with the peak hour of wastewater flow?) and the antecedent conditions (does the storm follow other storms?). The antecedent condition factor can affect peak flows in two ways: higher antecedent rainfall saturates the soil and increases the percentage of rain entering the sewers as I/I, and previous storms may still be contributing I/I, including groundwater infiltration, when the design storm occurs. Conservative assumptions regarding the antecedent conditions and the timing of the design storm (such as assuming peak I/I coincidental with peak dry weather flow) can add an additional level of conservatism. The continuous simulation approach addresses these factors by explicitly simulating the effects of antecedent conditions, storm duration, storm timing, and sequences of storms. Thus, the output of the continuous simulation is a design "event" that produces a total peak flow having the desired return period, which consists not only of a storm (i.e. rainfall), but also the storm timing and antecedent conditions.

It is important to realize that the characteristics of the event that generates the desired return period peak flow are not the same for all parts of the sewer system. For example, a short-duration, high-intensity storm will be more critical for a sewer serving a small area in which I/I occurs very quickly in response to rainfall. A longer storm with lower rainfall intensities is generally more critical for sewers serving larger areas and where the I/I response to rainfall is slower and takes longer to reach the sewer. Since this study is focused on the interceptors, continuous simulations were performed for locations that represent typical interceptor flows. Based on location and availability of flow monitoring data for use in calibrating models, three sites were selected for conducting continuous simulations:

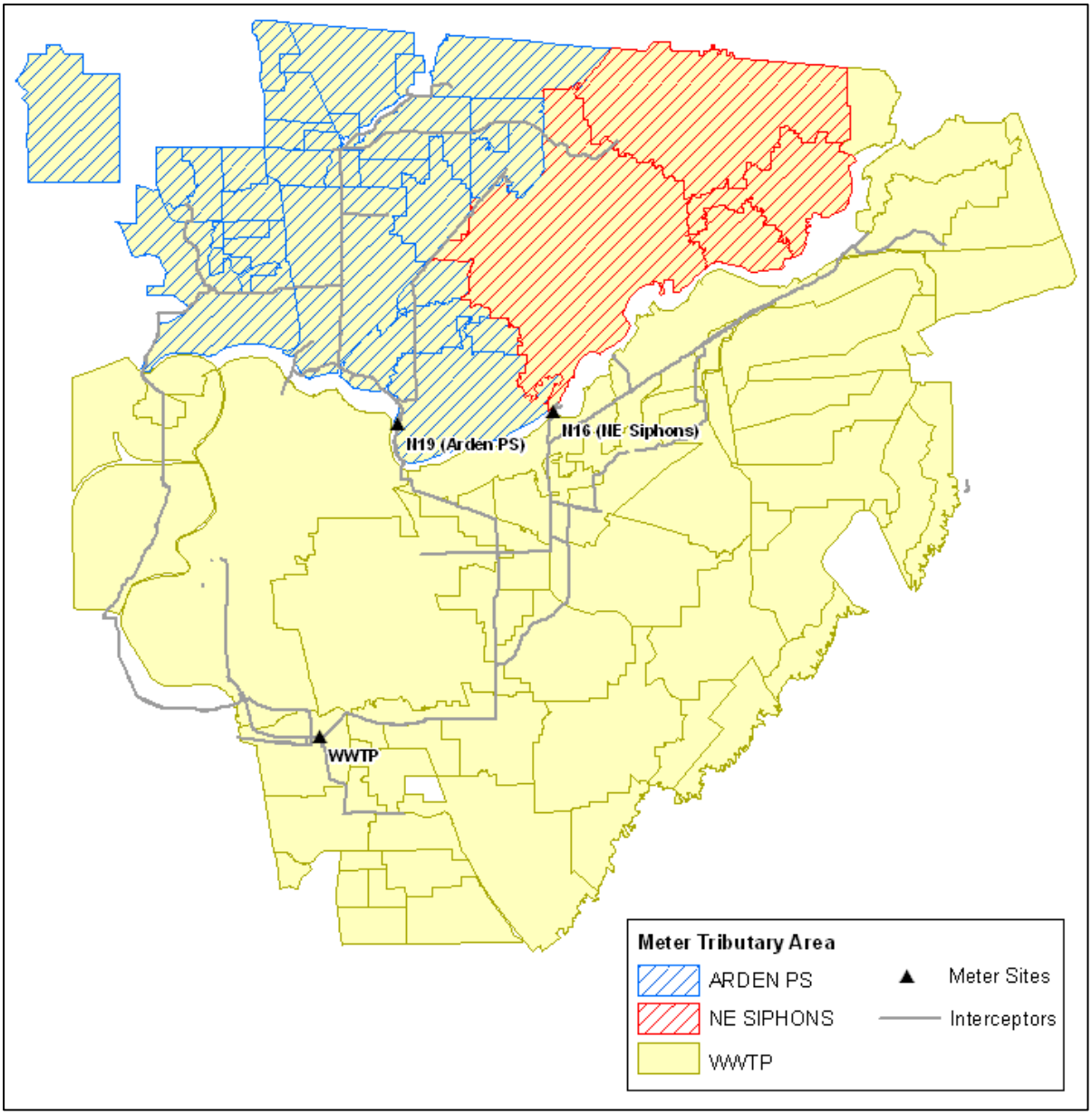
- The influent to the Sacramento Regional Wastewater Treatment Plant (SRWTP), minus the flow from the City of Sacramento combined sewer system
- The Arden Pump Station (Arden)
- The Northeast Siphons (NE Siphons)

The Arden and NE Siphons each serve approximately 60 square mile service areas, while the SRWTP serves about 250 square miles. Figure 2.1 shows the locations of the three sites. The Arden and NE Siphons sites were of primary interest since they represent interceptor sites on two major portions of the service area. The SRWTP site, being at the downstream end of the system, provides a boundary condition.

The continuous simulation analysis for this study utilized a custom hydrologic model called "Program for I/I Continuous Simulation" (PICS) developed by the RMC team and used in many previous projects for other agencies. PICS computes continuous flows at a single site, based on information about the characteristics of the tributary service area. It does not explicitly route flows through a network of sewers, although the effects of routing are accounted for through various parameters that are calibrated to match observed flows. Following calibration of PICS models for each of the three sites (as described in the following section), the models were run for the entire 72-year historical record for hourly rainfall at the downtown Sacramento rain gauge. Because PICS does not explicitly route flows through the existing sewers, it does not simulate overflows that could result from insufficient sewer capacity during extreme events. PICS implicitly assumes that sufficient hydraulic capacity is (or will be) available in the sewers to convey all peak flows to the site being modeled. This assumption is appropriate for the purposes of this study, since the implication is that sewers will eventually be upsized or relieved to convey the peak flows resulting from the selected design events.

The resulting 72 years of hourly flows from PICS were then processed through another custom program called "Model for Optimization of Storage and Treatment (MOST) to develop statistics on the return periods of historical events. As the name of the program implies, MOST is often used to determine how much storage is required to reduce peak flows to a specified maximum treatment rate. For this study, however, MOST was used only to rank historical events and estimate their return periods in terms of peak flow. From the output of MOST, it was possible to select historical events corresponding to any desired return period.

Figure 2.1 Continuous Simulation Monitoring Sites



Note: Map includes future (currently undeveloped) sewersheds; however, the areas of those sheds were not included for model calibration. The map also represents the configuration of the system during the PICS model calibration period (see discussion in next section of TM), prior to start of operation of the Upper Northwest and Lower Northwest Interceptors.

3.0 CONTINUOUS SIMULATION MODEL CALIBRATION

The calibration of the PICS models consisted of determining the "best-fit" values for the following variables:

- Average Dry Weather Flow (DWF), based on recent flow measurements during dry weather conditions.
- DWF Hourly Multipliers, again based on recent flow measurements during a typical weekday.
- Soil Moisture Index (SMI) decrement, which is the rate of decrease of SMI during dry periods between storms. SMI is similar to an antecedent rainfall index, and rises and falls during the wet weather season depending on the amount of rainfall (which increases the index) and the time that has passed without rainfall (which decreases the index).
- Groundwater Infiltration (GWI) Factor: factor used to compute GWI as a function of SMI.
- SMI vs. Rt Parameters: determines percentage of rainfall entering sewers (Rt) as a function of SMI. Generally serves to increase Rt during events having high SMI (i.e., high antecedent rainfall).
- Unit Hydrograph Factors: time to peak and recession constants for three (fast, medium, and slow response) unit hydrographs.
- Rt Allocation Factors: Allocates Rt into fast, medium, and slow unit hydrographs as a function of Rt. Effectively changes the shape of the wet weather hydrographs so that they have slower response and longer recessions during storms with high SMI.

The results of the calibrations of PICS models at SRWTP, Arden, and NE Siphons are included in Appendices A, B, and C. For each site, the calibration parameters are illustrated on the first two pages followed by comparison plots between observed and modeled daily flows and hourly flows covering the calibration period of October 2005 through April 2006. This was a good calibration period that included several storms of various sizes occurring under a range of antecedent rainfall (SMI) conditions, including a very large storm on December 31, 2005. The area-weighted rainfall for the tributary service areas of the three sites was obtained from gauge-adjusted radar rainfall data at a 2 kilometer resolution. Monitoring data was complete with the exception of a few hours on December 31 at the NE Siphons site.

Overall, the calibrations were considered to be very good for this type of model. It is typically more difficult to match flows for a series of events with changing antecedent conditions than it is to match flows in a single event. Yet all three models were able to reasonably replicate the gauged flows and volumes throughout the calibration period.

4.0 DESIGN AND PERFORMANCE STORMS

Following the calibrations, PICS and MOST were run using the 72-year hourly rainfall record at the Downtown Sacramento rain gauge, as provided by SRCSD staff. The MOST output was then queried to identify the historical storms that would be expected to generate the highest peak flows at each site. Note that the peak flow from a given event depends not only on the intensity and duration of rainfall, but also the antecedent (SMI) conditions and the timing of the storm relative to the daily diurnal DWF pattern.

Table 2.1 lists the dates of the events that generated the highest peak flows, and the corresponding rank and return period of those events at each of the three sites. Note that the rankings and return periods for a given event can and do vary by site, due to differences in the flow response characteristics of the tributary areas. In general, the event rankings for the Arden and NE Siphon sites were very similar. At the SRWTP site, some of the events ranked quite differently than they did at the two other sites. This finding is not surprising, given the much larger size of the tributary area. Since the purpose of this study is to identify storms for interceptor modeling, the storm rankings for the Arden and NE Siphon sites were given greater consideration.

Table 2.1: Event Rankings and Return Periods

Storm Date	RANK			RETURN PERIOD		
	Arden	NE Siphon S	RWTP	Arden	NE Siphon S	RWTP
2/17/1986	1	1	1	73.0	73.0	73.0
1/13/1993	2	3	6	36.5	24.3	12.2
1/21/1943	3	2	13	24.3	36.5	5.6
2/27/1940	4	9	4	18.3	8.1	18.3
4/2/1958	5	5	2	14.6	14.6	36.5
12/31/2005	6	6	11	12.2	12.2	6.6
10/13/1962	7	4	7	10.4	18.3	10.4
3/21/1937	8	14	16	9.1	5.2	4.6
12/23/1955	9	13	3	8.1	5.6	24.3
3/13/1983	10	19	5	7.3	3.8	14.6
4/4/1941	11	8	18	6.6	9.1	4.1
1/5/1982	12	7	14	6.1	10.4	5.2
2/3/1998	13	18	9	5.6	4.1	8.1
3/31/1982	14	16	---	5.2	4.6	---
1/10/1995	15	10	10	4.9	7.3	7.3
1/12/1990	16	15	---	4.6	4.9	---
1/22/1997	17	11	---	4.3	6.6	---
1/21/1967	18	12	---	4.1	6.1	---
2/19/1958	19	---	12	3.8	---	6.1
12/25/1983	20	---	---	3.7	---	---
1/26/1997	---	17	15	---	4.3	4.9
2/7/1983	---	20	---	---	3.7	---
1/17/1978	---	---	8	---	---	9.1
2/14/2000	---	---	17	---	---	4.3
1/24/2000	---	---	19	---	---	3.8
2/14/1938	---	---	20	---	---	3.7

The events were then reviewed for consideration as candidates for design and performance storms. Desirable characteristics for design and performance storms include:

- **Appropriate return periods.** A 5-year return period for performance storms and 10-year return period for design storms were used as targets.

- **High-SMI events.** Storms that occurred under high antecedent rainfall conditions (high SMI) that maximize I/I response are preferable. When these storms are used in a dynamic hydraulic model to assess interceptor capacities, the I/I response parameters in the hydraulic model must be adjusted to be consistent with those in the continuous simulation model. But the I/I response parameters vary from storm to storm in the continuous simulation model depending on the antecedent conditions. The best way to ensure consistency between the models is to calibrate the hydraulic model under high-SMI conditions, and apply a storm that was selected under high-SMI conditions from the continuous simulations.

- **Events suitable for large tributary areas.** The selected storms will be used to simulate flows in interceptors rather than smaller trunks and mains. In general, the critical events for larger areas tend to be longer in duration and lower in intensity than the critical events for smaller areas. Because the PICS models were calibrated to flows observed at interceptor sites, those types of storms tended to be the ones with high rankings. However, storms with similar rankings can have different combinations of intensity and duration that produce approximately the same peak flows. In those cases, storms with lower peak rainfall intensities are preferable. The reason for this is that storms with short durations of very high rainfall intensity are typically more localized in extent due to the size of the storm cells involved. At the extreme is the small cloudburst as opposed to the large frontal storm. Avoiding events with very high intensities eliminates cloudburst events that would not be applicable to large areas.

- **Daytime events.** Rainfall events which occur during daytime hours result in peak flows that occur at or near the hour in which peak DWF occurs. This is preferable from a modeling standpoint because it ensures that the peak wet weather flow is always higher than the peak dry weather flow, even in areas having relatively little I/I.

The events in Table 2.1 were screened using the above-noted considerations, and specific events were selected as most appropriate for use as potential design and performance storms.

The event of December 31, 2005 (see Figure 2.2) was selected as an appropriate potential design storm event. This event was estimated to have a 12-year return period at both interceptor sites, had a high SMI, was a long-duration event with moderate rainfall intensities, and peaked in the morning hours. Figure 2.3 shows a set of depth-duration-frequency (DDF) curves comparing the rainfall depths for various periods within the storm (from 1 hour to 12 hours) to the rainfall depths corresponding to 2, 5, and 10-year storms

from the City and County of Sacramento Drainage Manual. The figure shows that the December 31, 2005 storm had the highest return period at 12 hours (slightly greater than 10 years), but was less critical at shorter durations (at or under a 5-year return period). Thus, this event definitely meets the criteria of suitability for a large tributary area – long duration with moderate intensities. As a bonus, it was a recent event that occurred during the calibration period. It is always desirable (but seldom possible) to select a calibration event as a design event, since it greatly increases confidence in the modeling results. In addition, the event is more “real” in that most people can recall it and have a feel for its magnitude from personal experience.

The event of March 31, 1982 was selected as an appropriate potential performance storm event (see Figure 2.4). This event was estimated to have a return period of 5.1 years at the Arden site and 4.5 years at the NE Siphon site. It also had a high SMI, was a long-duration event with moderate rainfall intensities, and peaked in the morning hours. As shown on Figure 2.3, the rainfall intensities in this event were also moderate and were more critical over the longer durations.

Table 2.2 presents the hourly rainfall depths for both storms.

Figure 2.2 Potential Design Storm Event: December 31, 2005

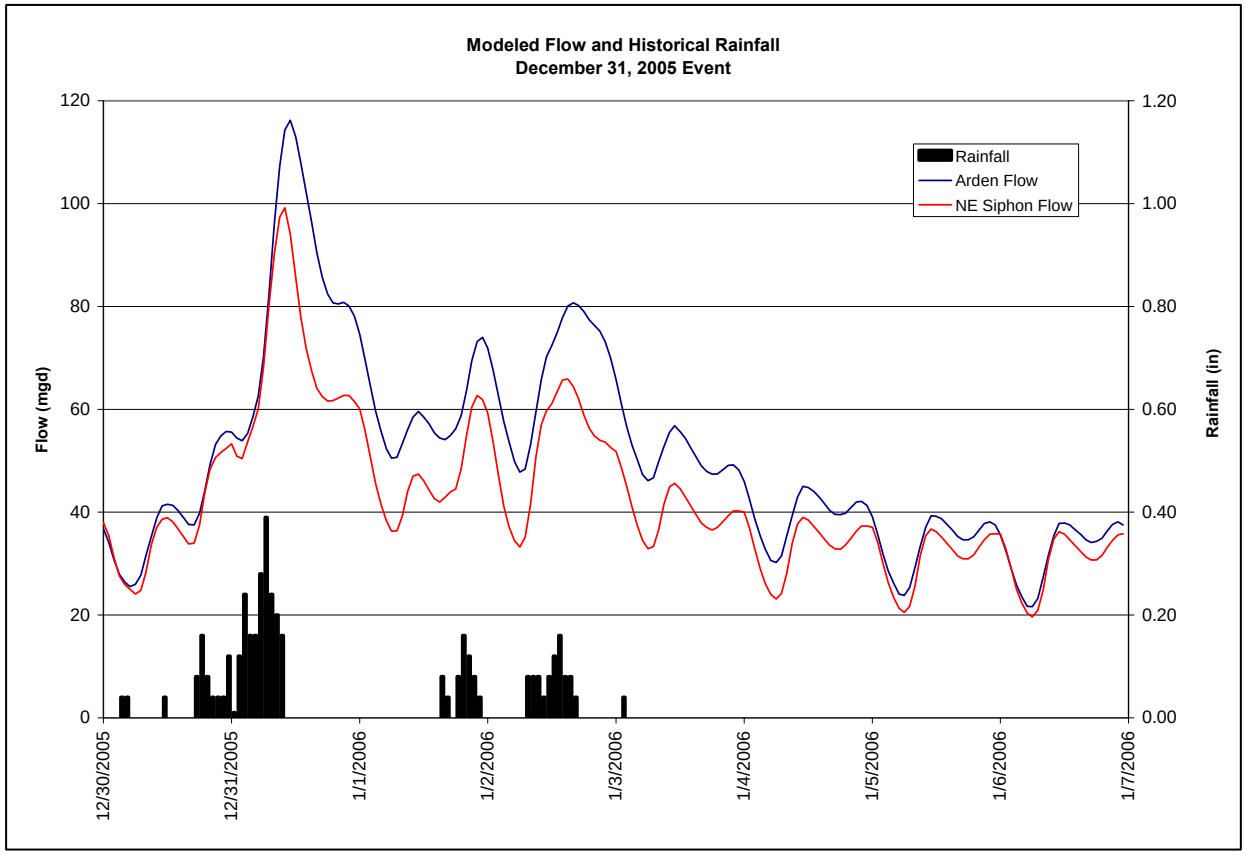


Figure 2.3 Rainfall Return Periods of Selected Historical Events

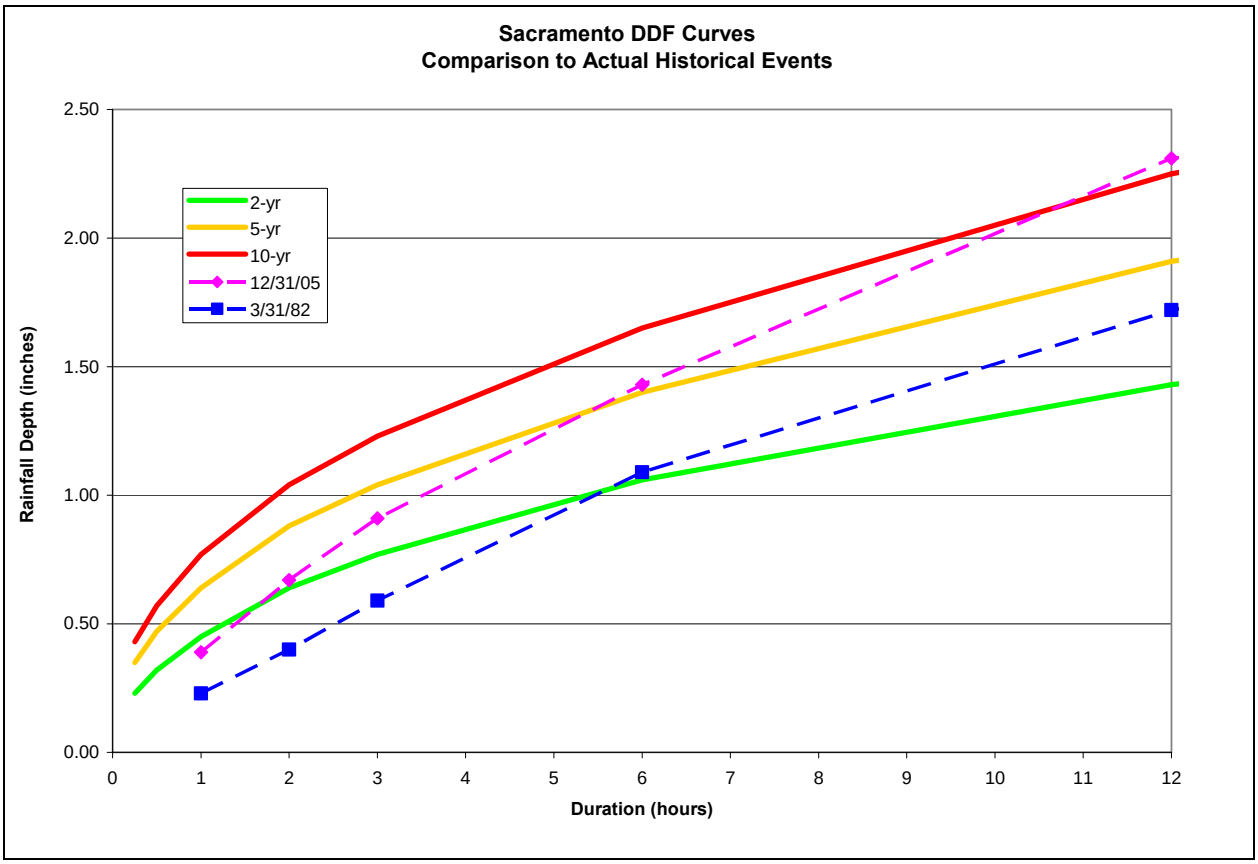


Figure 2.4 Potential Performance Storm Event: March 31, 1982

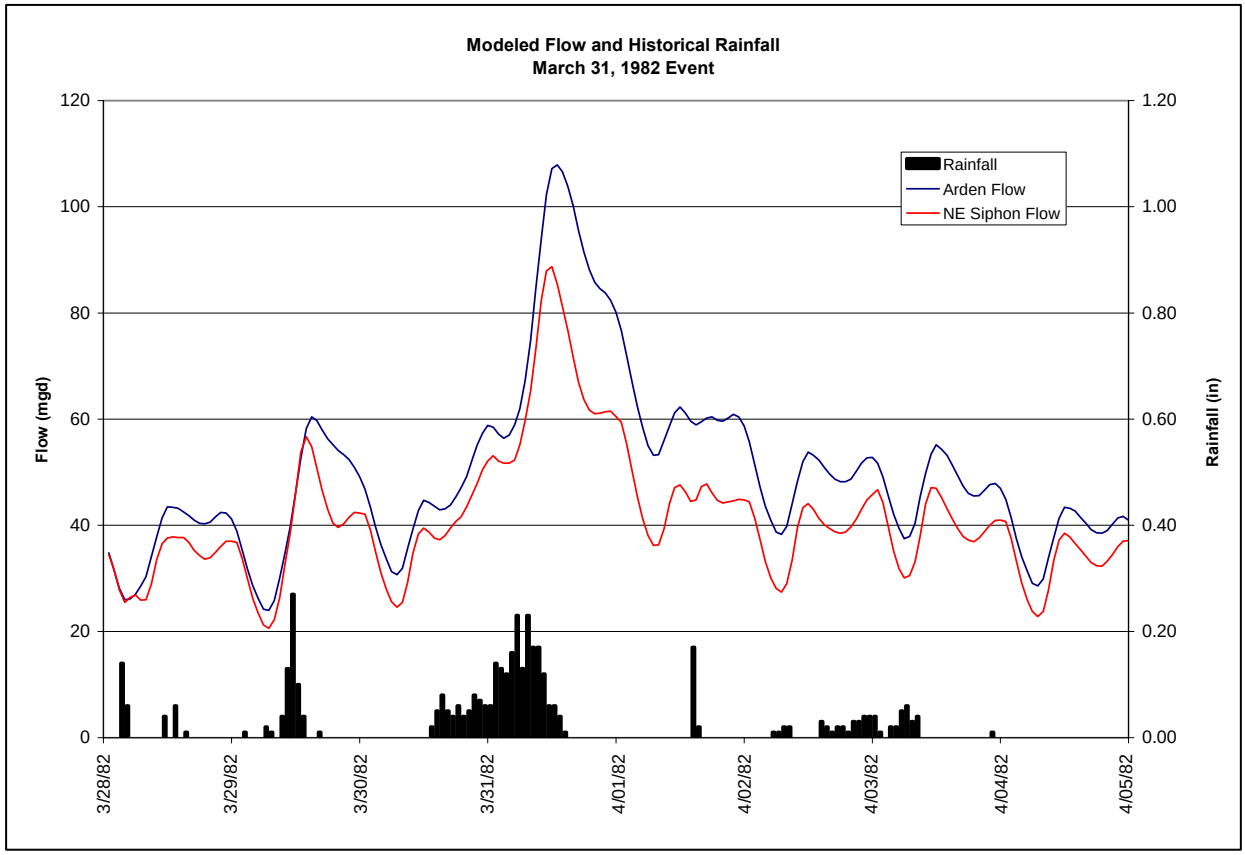


Table 2.2: Hourly Rainfall Depths for Potential Design and Performance Storms

December 31, 2005 Storm			March 31, 1982 Storm	
Date/Time	Rainfall (in)		Date/Time	Rainfall (in)
12/30/05 1:00 PM	0.00		3/30/82 1:00 PM	0.02
12/30/05 2:00 PM	0.00		3/30/82 2:00 PM	0.05
12/30/05 3:00 PM	0.00		3/30/82 3:00 PM	0.08
12/30/05 4:00 PM	0.00		3/30/82 4:00 PM	0.05
12/30/05 5:00 PM	0.08		3/30/82 5:00 PM	0.04
12/30/05 6:00 PM	0.16		3/30/82 6:00 PM	0.06
12/30/05 7:00 PM	0.08		3/30/82 7:00 PM	0.04
12/30/05 8:00 PM	0.04		3/30/82 8:00 PM	0.05
12/30/05 9:00 PM	0.04		3/30/82 9:00 PM	0.08
12/30/05 10:00 PM	0.04		3/30/82 10:00 PM	0.07
12/30/05 11:00 PM	0.12		3/30/82 11:00 PM	0.06
12/31/05 12:00 AM	0.01		3/31/82 12:00 AM	0.06
12/31/05 1:00 AM	0.12		3/31/82 1:00 AM	0.14
12/31/05 2:00 AM	0.24		3/31/82 2:00 AM	0.13
12/31/05 3:00 AM	0.16		3/31/82 3:00 AM	0.12
12/31/05 4:00 AM	0.16		3/31/82 4:00 AM	0.16
12/31/05 5:00 AM	0.28		3/31/82 5:00 AM	0.23
12/31/05 6:00 AM	0.39		3/31/82 6:00 AM	0.13
12/31/05 7:00 AM	0.24		3/31/82 7:00 AM	0.23
12/31/05 8:00 AM	0.20		3/31/82 8:00 AM	0.17
12/31/05 9:00 AM	0.16		3/31/82 9:00 AM	0.17
12/31/05 10:00 AM	0.00		3/31/82 10:00 AM	0.12
12/31/05 11:00 AM	0.00		3/31/82 11:00 AM	0.06
12/31/05 12:00 PM	0.00		3/31/82 12:00 PM	0.06
12/31/05 1:00 PM	0.00		3/31/82 1:00 PM	0.04
12/31/05 2:00 PM	0.00		3/31/82 2:00 PM	**0.01**
Total Rainfall	**2.52**		**Total Rainfall**	**2.43**
Max 12-hr Rainfall	**2.12**		**Max 12-hr Rainfall**	**1.72**

When applying the design and performance events in a dynamic model, it is appropriate to add additional flow to the normal dry weather flow to represent the elevated flow that existed prior to the start of the rainfall event. The elevated flow is due to increased groundwater infiltration and longer-duration rainfall-dependent I/I resulting from prior storms. For example, the simulated amount of additional flow at the SRWTP at the start of both the December 31, 2005 and March 31, 1982 storm events was approximately 28 mgd. Therefore, when modeling the design and performance events, some additional amount of flow will need to be incorporated as an antecedent I/I condition. The method for distributing this flow to model sewersheds should be based on available flow monitoring data to the extent possible, and will be developed as part of model calibration.

It is worth noting that the 5- and 10-year return period synthetic storms that were used in the SASD Master Plan were developed to be appropriate for use in smaller areas and thus

were short in duration (6 hours) with relatively intense peak rainfall. These synthetic storms were run through the continuous simulation model to determine the return period of the peak flows that they would produce at the Arden and NE Siphons interceptor sites. The model confirmed that these synthetic storms are less critical for interceptor analysis than the potential design and performance storms identified through the continuous simulation modeling. The synthetic 10-year storm produced peak flows with 4 to 6 year return periods while the synthetic 5-year storm produced peak flows with 2 to 3 year return periods at the modeled interceptor sites.

5.0 RAINFALL SPATIAL VARIATION

As noted above, the storms selected as potential design and performance events were long-duration, moderate-intensity rainfall events, characteristic of large frontal storms that would be expected to cover the entire SRCSD service area. In such storms, variations in rainfall across the service area can be expected to occur to some extent, but are not very significant, particularly over the long durations that are critical for interceptor analysis. Because of this, no modifications of the design storm event are recommended to account for spatial variation due to storm cell size (i.e., no need to apply depth-area reduction factors or equivalent).

Another potential cause of spatial rainfall variation is topography. An orographic effect tends to increase rainfall at higher elevations. The City and County of Sacramento Drainage Manual (Manual) indicates the existence of an orographic effect at elevations over 100 feet, which results in higher annual rainfall amounts in the northeast portion of the County (see Figure 2.5). The Manual provides adjustment factors based on elevation and return period that can be applied to adjust the amount of rainfall for storms of various durations (see Table 2.3). These factors should be applied as follows to adjust the design and performance storms in areas with higher elevations:

- The average elevation of sewersheds (or groups of sewersheds with similar elevations) in the northeast portion of the service area should be determined from topographic maps.

- The adjustment factors from Table 2.3 should be used to determine a percentage increase in 5-year and 10-year 12-hour rainfall depths from Table 2.4 (design rainfall depths from the Manual) for each sewershed group. That percentage increase should be used to scale up the design and performance events identified in this TM. The percentage increase for the 5-year event should be applied to the performance event and the percentage increase for the 10-year event should be applied to the design event. Note that the same percentage should be applied to all durations in each event. For example, the design storm for a sewershed group with an average elevation of 300 feet would be scaled up by about 11 percent: [(300/1000)*0.82]/2.25.

Figure 2.5: Contours of Average Annual Rainfall
(from City and County of Sacramento Drainage Manual)

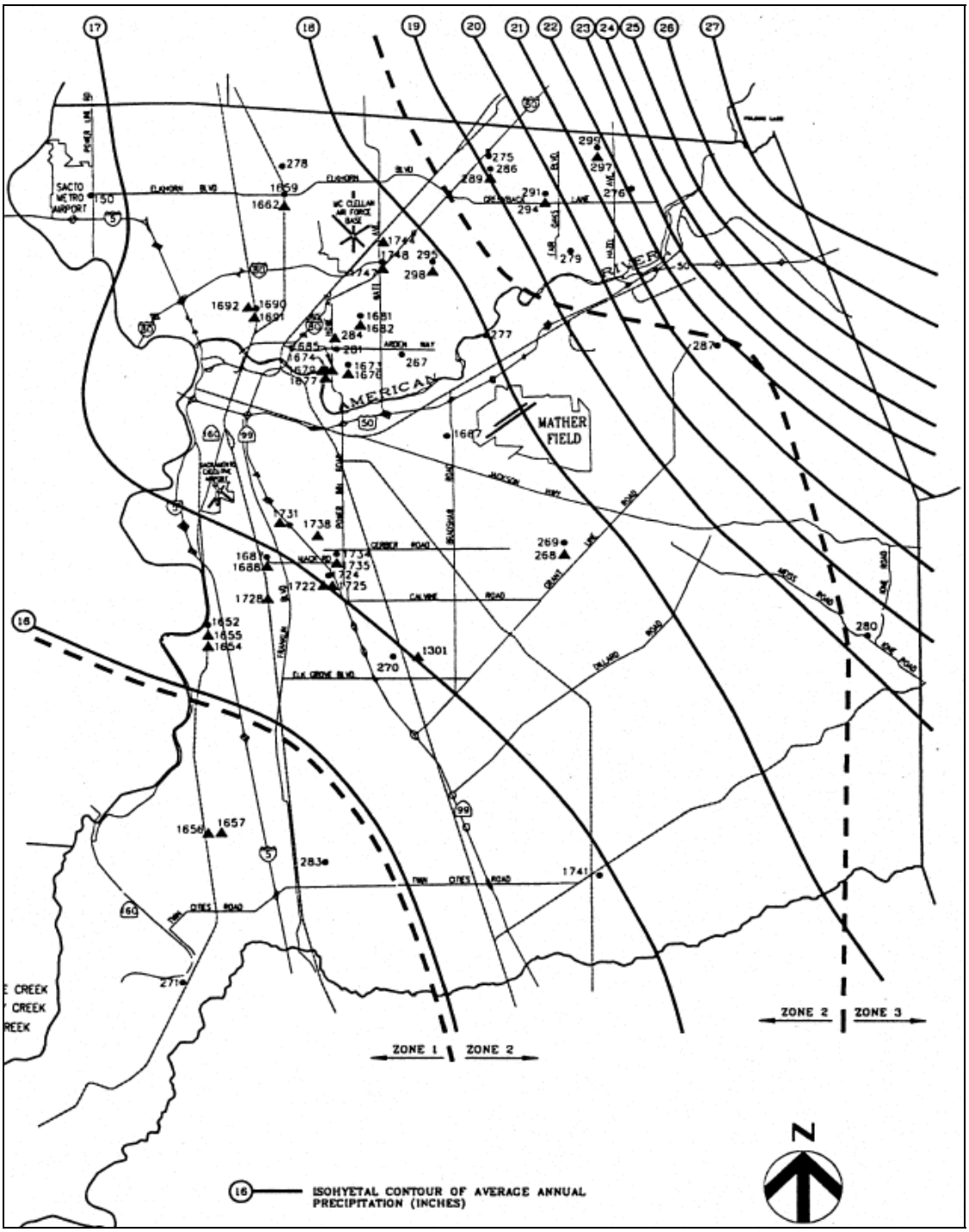


Table 2.3: Elevation Adjustment Factors
(from City and County of Sacramento Drainage Manual)

Freque					ncy (years)			
Duration	**2**	**5**	**10 25**	**50**		**100**	**200**	**500**
5 min	0.007	0.000	-0.003	-0.007	-0.017	-0.023	-0.027	-0.037
10 min	0.007	0.003	0.000	-0.010	-0.020	-0.027	-0.037	-0.050
15 min	0.017	0.013	0.013	0.003	0.000	-0.007	-0.013	-0.027
30 min	0.030	0.037	0.043	0.043	0.040	0.043	0.040	0.037
1 hour	0.063	0.087	0.100	0.120	0.133	0.137	0.157	0.173
2 hours	0.107	0.157	0.193	0.230	0.260	0.287	0.313	0.350
3 hours	0.143	0.220	0.263	0.327	0.373	0.413	0.457	0.513
6 hours	0.230	0.357	0.433	0.540	0.593	0.733	0.757	0.850
12 hours	0.453	**0.663**	**0.820**	0.977	1.127	1.250	1.400	1.600
24 hours	0.700	1.037	1.240	1.547	1.783	1.983	2.200	2.500

Depth Increase (inches) = Elevation (ft) *Factor/1000

Table 2.4: Design Rainfall Depths (inches)
(from City and County of Sacramento Drainage Manual)

Freque					ncy (years)			
Duration	**2**	**5**	**10 25**	**50**		**100**	**200**	**500**
5 min	0.13	0.20	0.25	0.32	0.38	0.44	0.49	0.58
10 min	0.19	0.29	0.36	0.46	0.54	0.62	0.70	0.82
15 min	0.23	0.35	0.43	0.55	0.64	0.73	0.82	0.96
30 min	0.32	0.47	0.57	0.72	0.83	0.94	1.04	1.22
1 hour	0.45	0.64	0.77	0.94	1.07	1.21	1.33	1.53
2 hours	0.64	0.88	1.04	1.26	1.42	1.59	1.76	2.00
3 hours	0.77	1.04	1.23	1.47	1.66	1.85	2.03	2.31
6 hours	1.06	1.40	1.65	1.95	2.22	2.50	2.75	3.10
12 hours	1.43	**1.91**	**2.25**	2.67	3.00	3.30	3.60	4.00
24 hours	1.90	2.50	2.98	3.46	3.85	4.25	4.60	5.20

Note that the use of adjustment factors for a 12-hour rainfall duration, as opposed to shorter durations, was based on the fact that the design and performance events are most critical at the 12-hour duration. However, the resulting scaling factor is not highly sensitive to the duration selected within the range of 6 to 24 hours.

6.0 STORM MOVEMENT

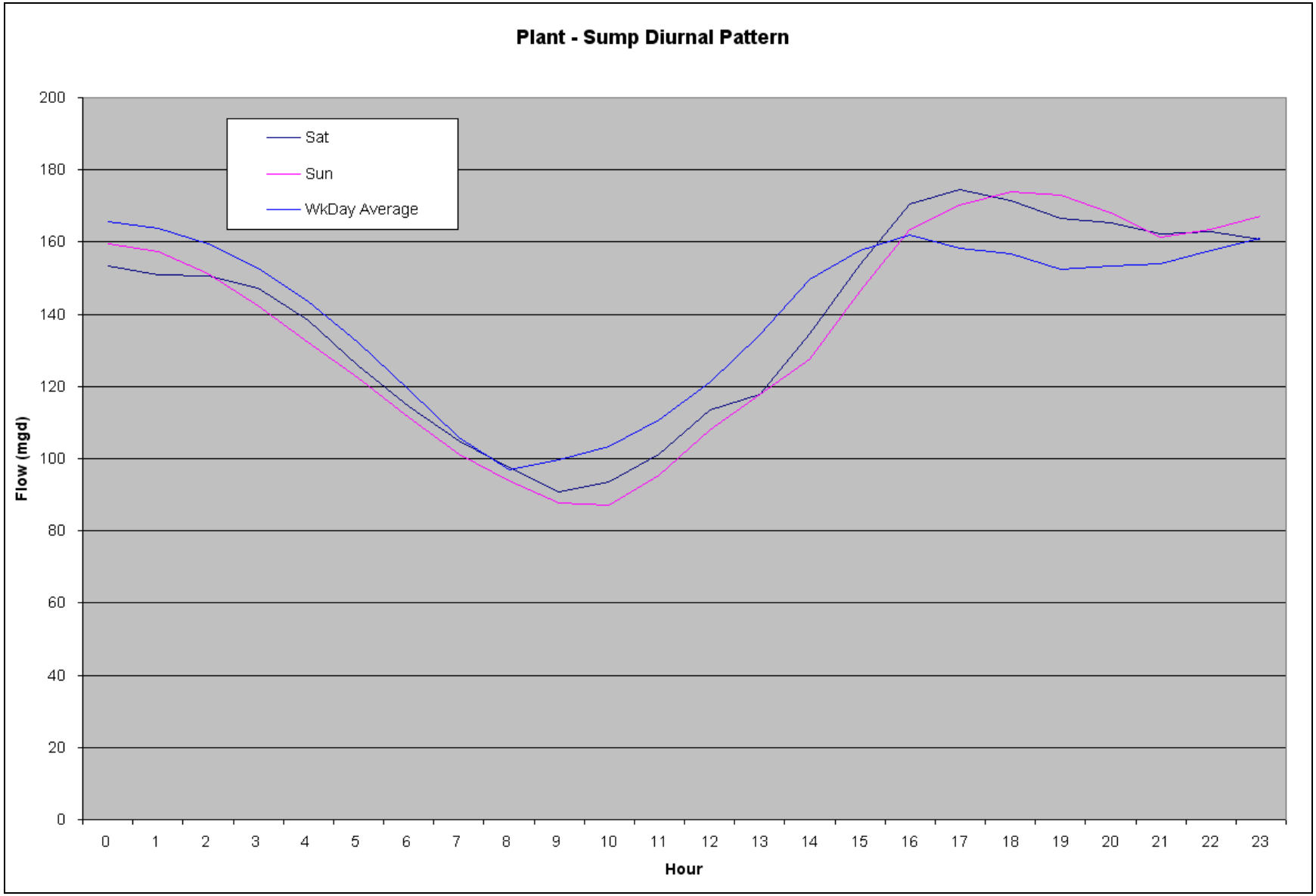
Design and performance storms are typically assumed to occur simultaneously throughout an entire service area. In other words, the storm is not shifted in time to represent the movement of the storm front across the service area. That is acceptable because fronts move across the area quickly enough that the assumption of simultaneous rainfall in all areas is reasonable. In very large service areas such as SRCSD, it is conceivable that shifting the storms in time to represent storm movement might be appropriate.

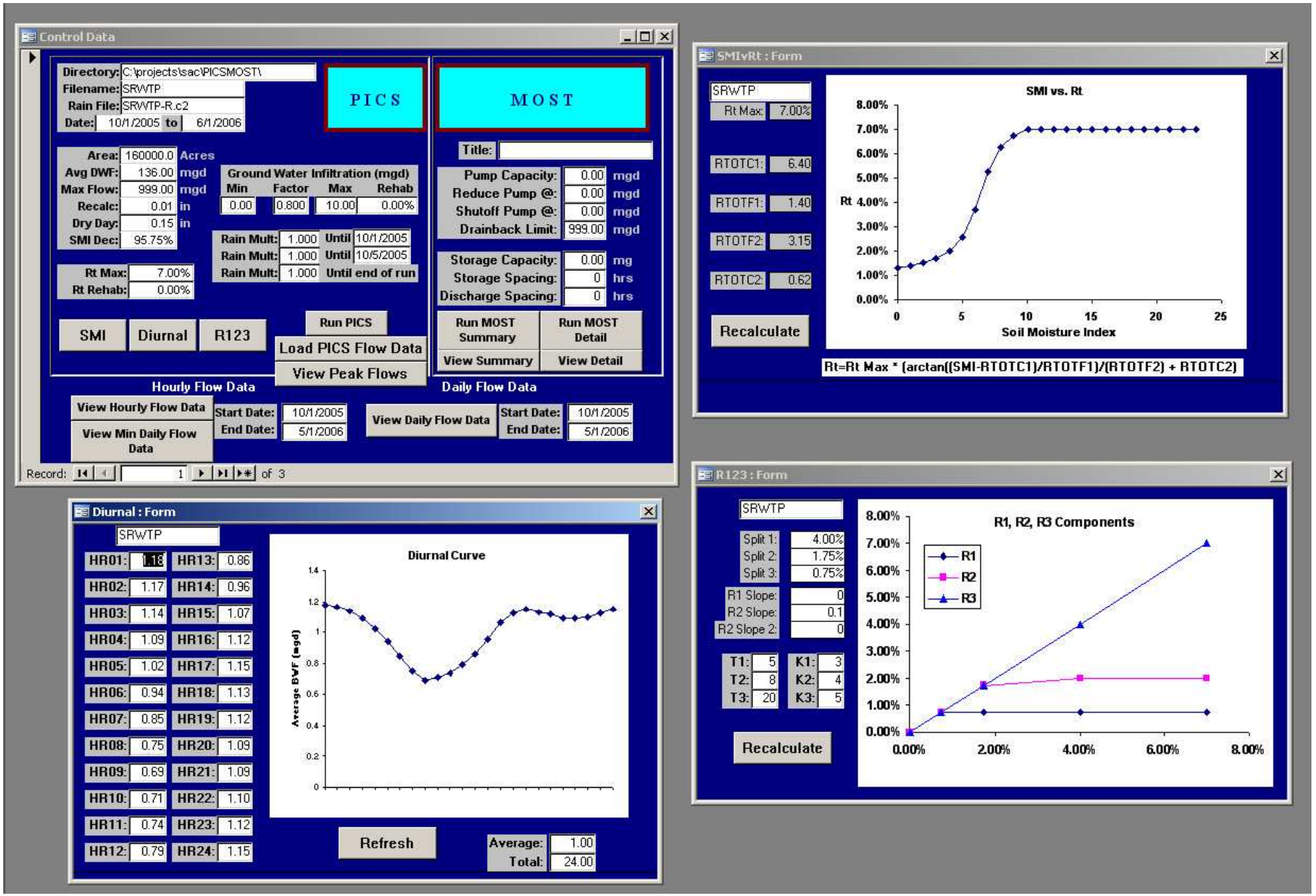
In order to determine if time-shifting of the design and performance storms would be appropriate, additional analysis would be required. The analysis would determine the characteristic speed and direction of major historical storm events using 2-kilometer, 15-minute resolution radar rainfall data. Several large frontal storms would need to be analyzed to determine if there is a dominant set of speed and direction characteristics. The suggested method for quantifying storm movement is to determine the time of occurrence of the center of mass of each storm event in each 2-kilometer pixel (i.e., time when half the total rainfall has occurred).

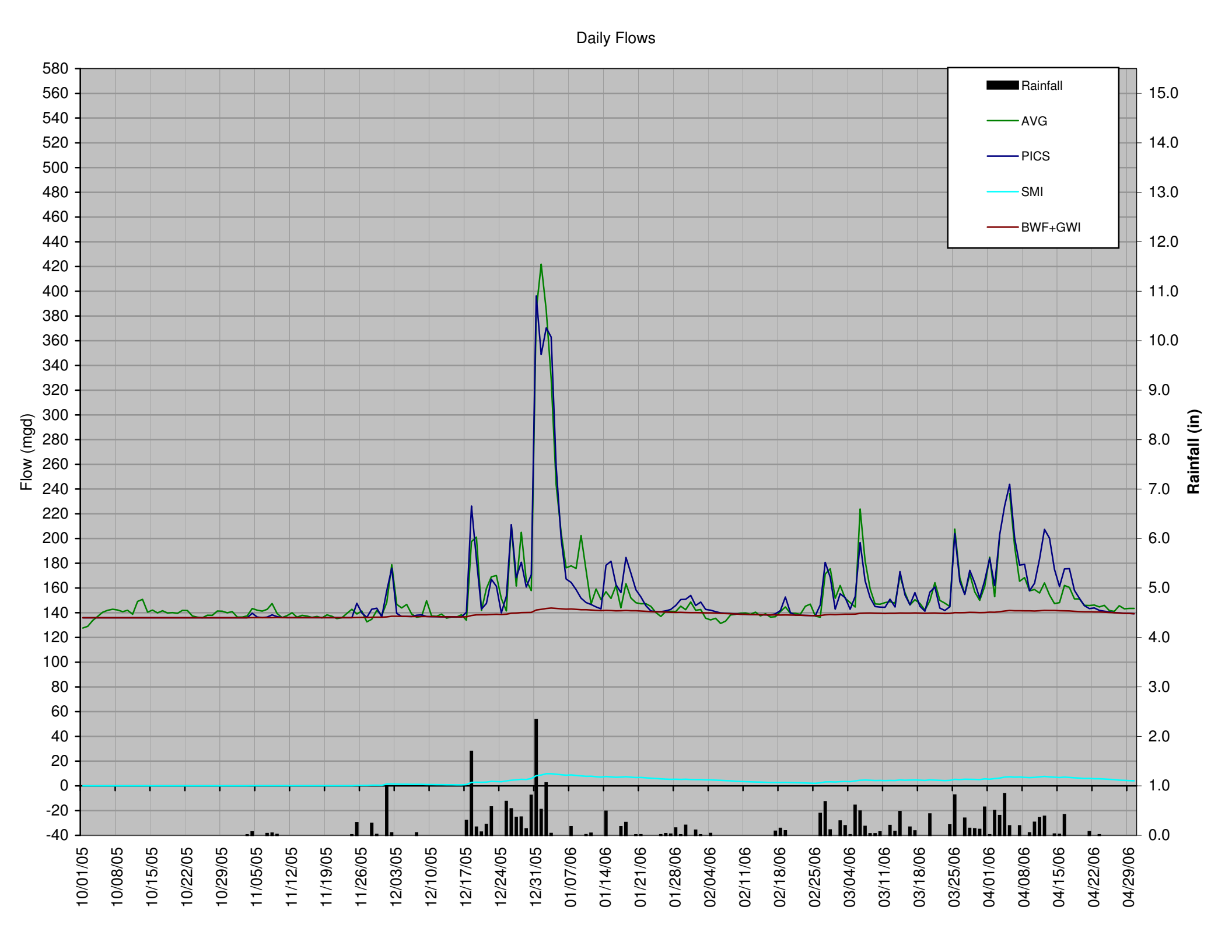
Once the dominant speed and direction characteristics have been determined, these characteristics should be tested by modeling the design and performance storms with the SRCSD dynamic hydraulic model. The peak flows throughout the interceptor system from these model runs should be compared to the peak flows from runs assuming simultaneous rainfall (i.e., no storm movement). If the test runs indicate that storm movement has a significant effect on peak flows, consideration should be given to including storm movement characteristics into the definitions of the design and performance storms. It is possible that the test runs would show that storm movement only has a significant effect on flows in certain downstream interceptors. In that case, the criteria for applying storm movement could specify that it be used only in specific situations where the affected interceptors are being evaluated.

Appendix A

CALIBRATION RESULTS FOR SRWTP SITE


Plant - Sump Diurnal Pattern
Sat
Sun
WkDay Average
Flow (mgd)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour


Control Data
Directory: C:\projects\sac\PICSMOST\
Filename: SRWTP
Rain File: SRWTP-R.c2
Date: 10/1/2005 to 6/1/2006
PICS
MOST
Area: 160000.0 Acres
Avg DWF: 136.00 mgd
Max Flow: 999.00 mgd
Recalc: 0.01 in
Dry Day: 0.15 in
SMI Dec: 95.75%
Ground Water Infiltration (mgd)
Min Factor Max Rehab
0.00 0.800 10.00 0.00%
Rain Mult: 1.000 Until 10/1/2005
Rain Mult: 1.000 Until 10/5/2005
Rain Mult: 1.000 Until end of run
Rt Max: 7.00%
Rt Rehab: 0.00%
SMI
Diurnal
R123
Run PICS
Load PICS Flow Data
View Peak Flows
Title:
Pump Capacity: 0.00 mgd
Reduce Pump @: 0.00 mgd
Shutoff Pump @: 0.00 mgd
Drainback Limit: 999.00 mgd
Storage Capacity: 0.00 mg
Storage Spacing: 0 hrs
Discharge Spacing: 0 hrs
Run MOST Summary
Run MOST Detail
View Summary
View Detail
Hourly Flow Data
View Hourly Flow Data
View Min Daily Flow Data
Start Date: 10/1/2005
End Date: 5/1/2006
Daily Flow Data
View Daily Flow Data
Start Date: 10/1/2005
End Date: 5/1/2006
Record: 1 of 3
SMIvRt : Form
SRWTP
Rt Max: 7.00%
RTOTC1: 6.40
RTOTF1: 1.40
RTOTF2: 3.15
RTOTC2: 0.62
Recalculate
SMI vs. Rt
Rt
Soil Moisture Index
Rt=Rt Max * (arctan([SMI-RTOTC1)/RTOTF1)/(RTOTF2) + RTOTC2)
Diurnal : Form
SRWTP
HR01: 1.18
HR02: 1.17
HR03: 1.14
HR04: 1.09
HR05: 1.02
HR06: 0.94
HR07: 0.85
HR08: 0.75
HR09: 0.69
HR10: 0.71
HR11: 0.74
HR12: 0.79
HR13: 0.86
HR14: 0.96
HR15: 1.07
HR16: 1.12
HR17: 1.15
HR18: 1.13
HR19: 1.12
HR20: 1.09
HR21: 1.09
HR22: 1.10
HR23: 1.12
HR24: 1.15
Diurnal Curve
Average BVF (mgd)
Refresh
Average: 1.00
Total: 24.00
R123 : Form
SRWTP
Split 1: 4.00%
Split 2: 1.75%
Split 3: 0.75%
R1 Slope: 0
R2 Slope: 0.1
R2 Slope 2: 0
T1: 5
T2: 8
T3: 20
K1: 3
K2: 4
K3: 5
Recalculate
R1, R2, R3 Components
R1
R2
R3


Daily Flows
Rainfall
AVG
PICS
SMI
BWF+GWI
Flow (mgd)
Rainfall (in)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
10/01/05
10/08/05
10/15/05
10/22/05
10/29/05
11/05/05
11/12/05
11/19/05
11/26/05
12/03/05
12/10/05
12/17/05
12/24/05
12/31/05
01/07/06
01/14/06
01/21/06
01/28/06
02/04/06
02/11/06
02/18/06
02/25/06
03/04/06
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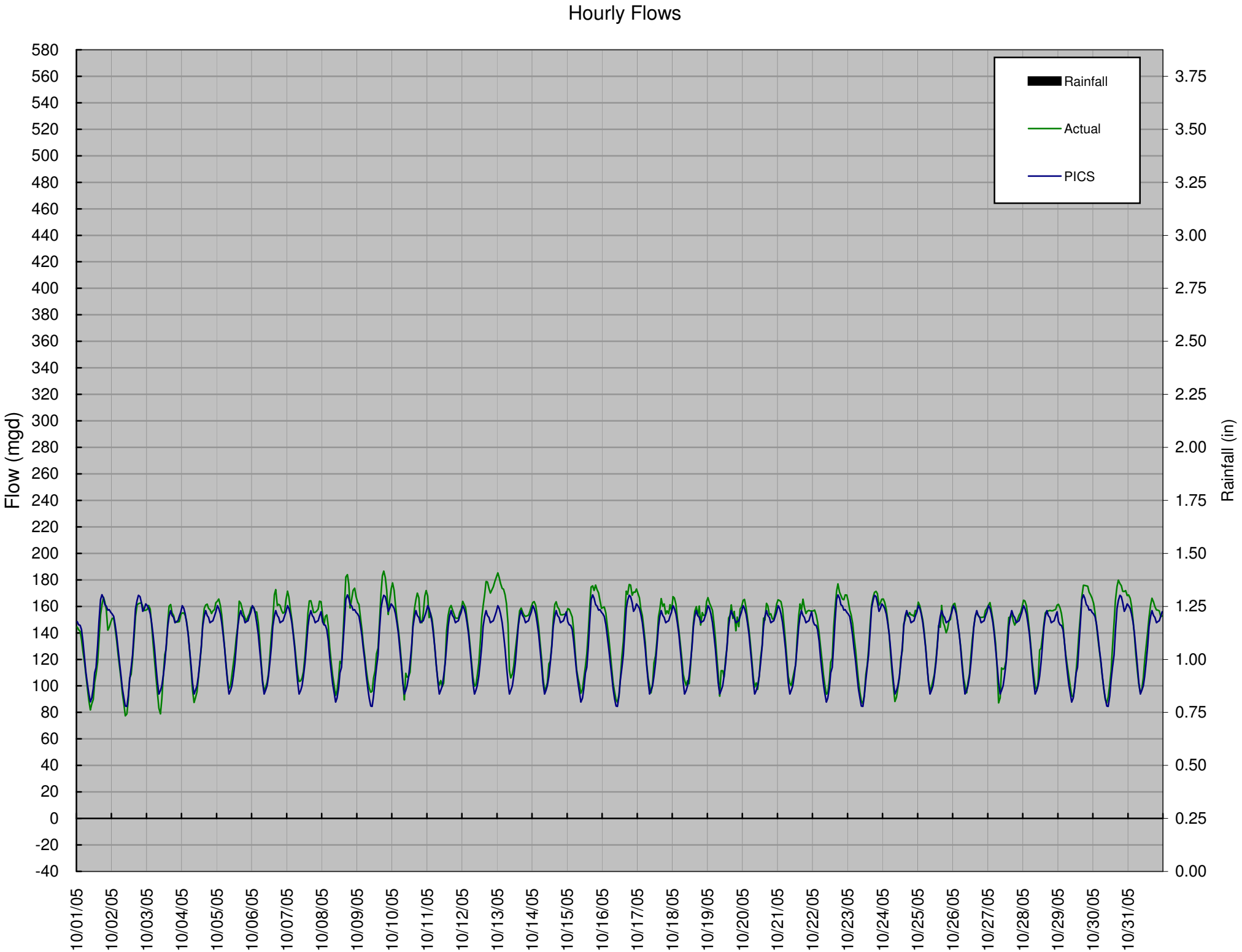
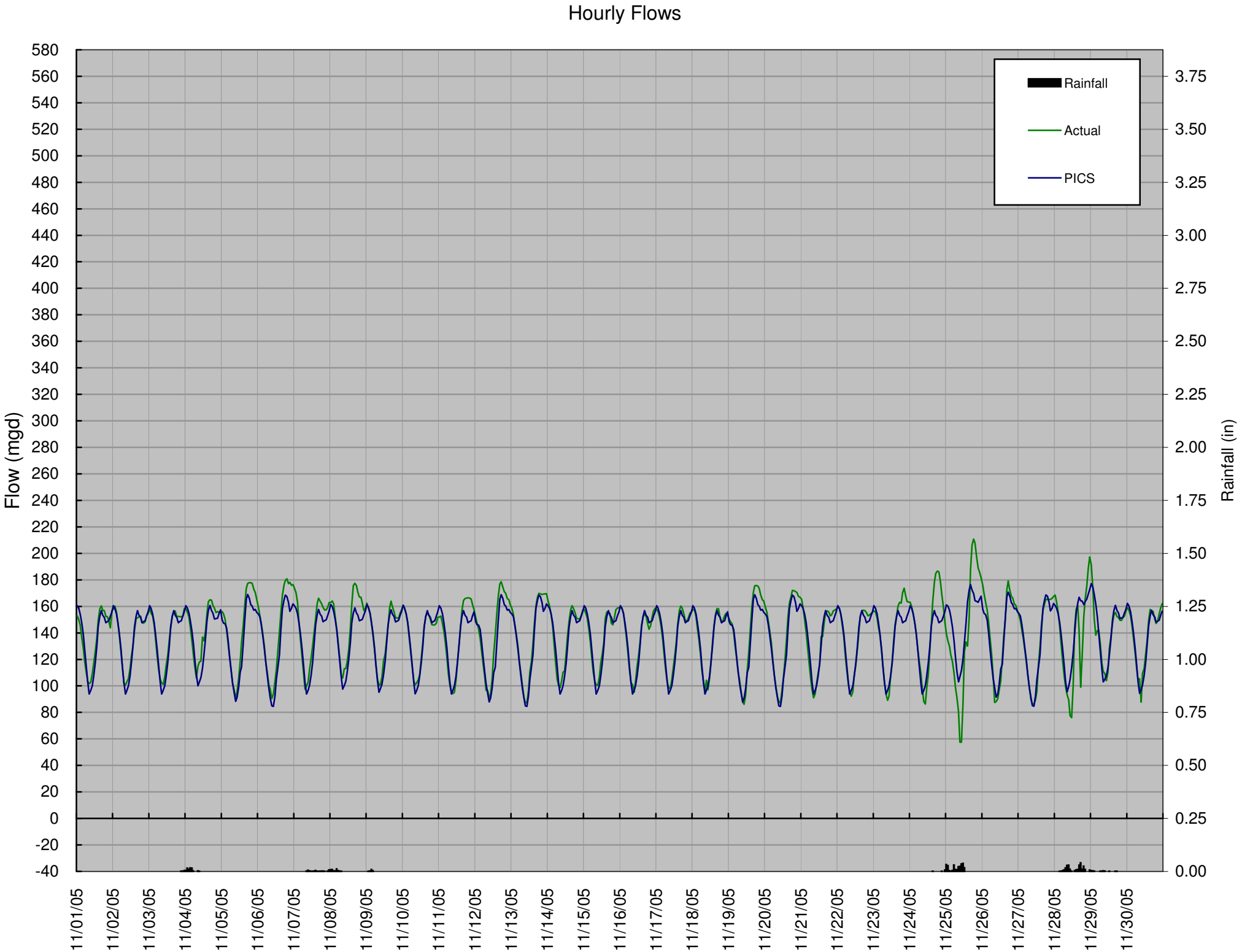
04/01/06
04/08/06
04/15/06
04/22/06
04/29/06


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
10/01/05
10/02/05
10/03/05
10/04/05
10/05/05
10/06/05
10/07/05
10/08/05
10/09/05
10/10/05
10/11/05
10/12/05
10/13/05
10/14/05
10/15/05
10/16/05
10/17/05
10/18/05
10/19/05
10/20/05
10/21/05
10/22/05
10/23/05
10/24/05
10/25/05
10/26/05
10/27/05
10/28/05
10/29/05
10/30/05
10/31/05


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
11/01/05
11/02/05
11/03/05
11/04/05
11/05/05
11/06/05
11/07/05
11/08/05
11/09/05
11/10/05
11/11/05
11/12/05
11/13/05
11/14/05
11/15/05
11/16/05
11/17/05
11/18/05
11/19/05
11/20/05
11/21/05
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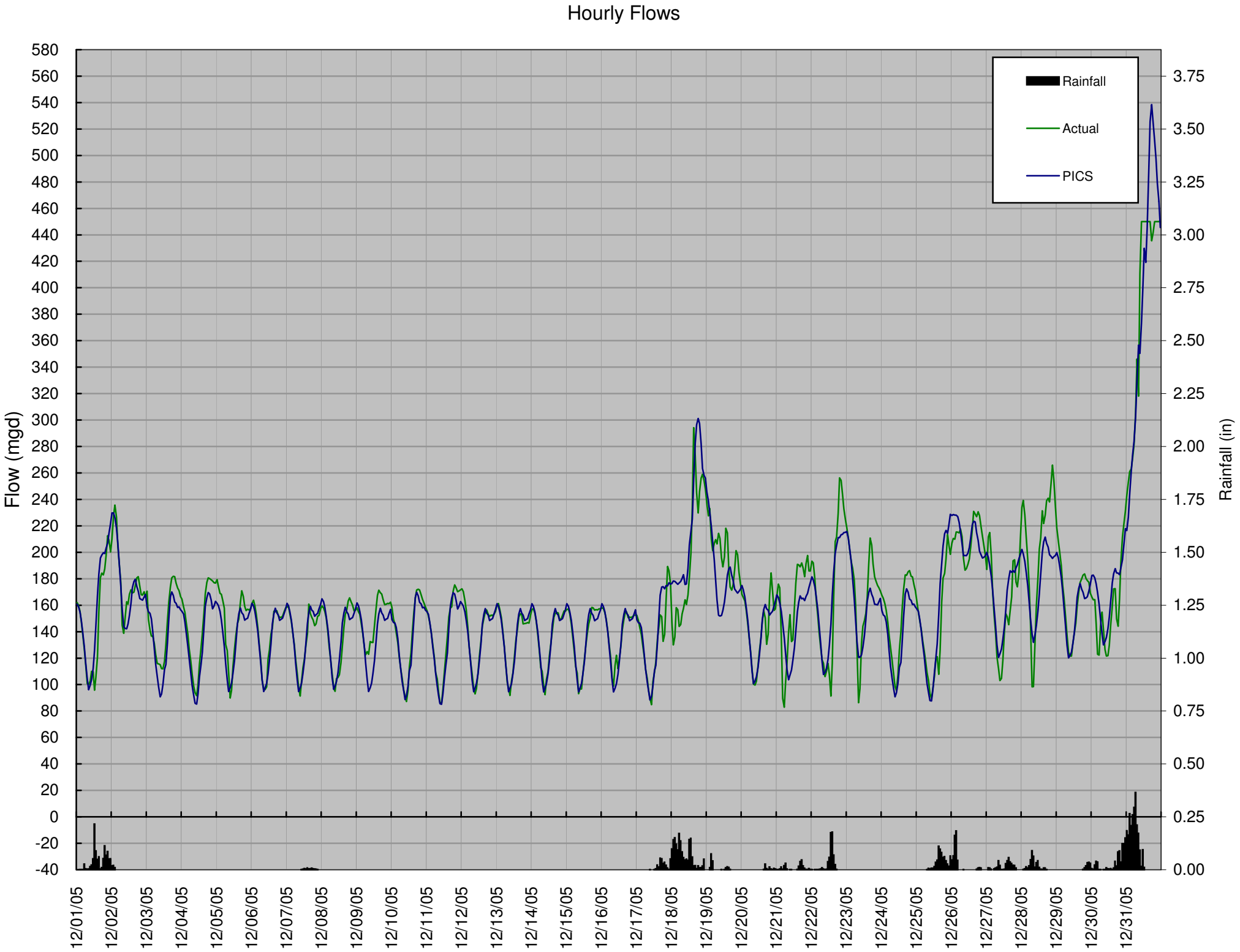
11/27/05
11/28/05
11/29/05
11/30/05


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
12/01/05
12/02/05
12/03/05
12/04/05
12/05/05
12/06/05
12/07/05
12/08/05
12/09/05
12/10/05
12/11/05
12/12/05
12/13/05
12/14/05
12/15/05
12/16/05
12/17/05
12/18/05
12/19/05
12/20/05
12/21/05
12/22/05
12/23/05
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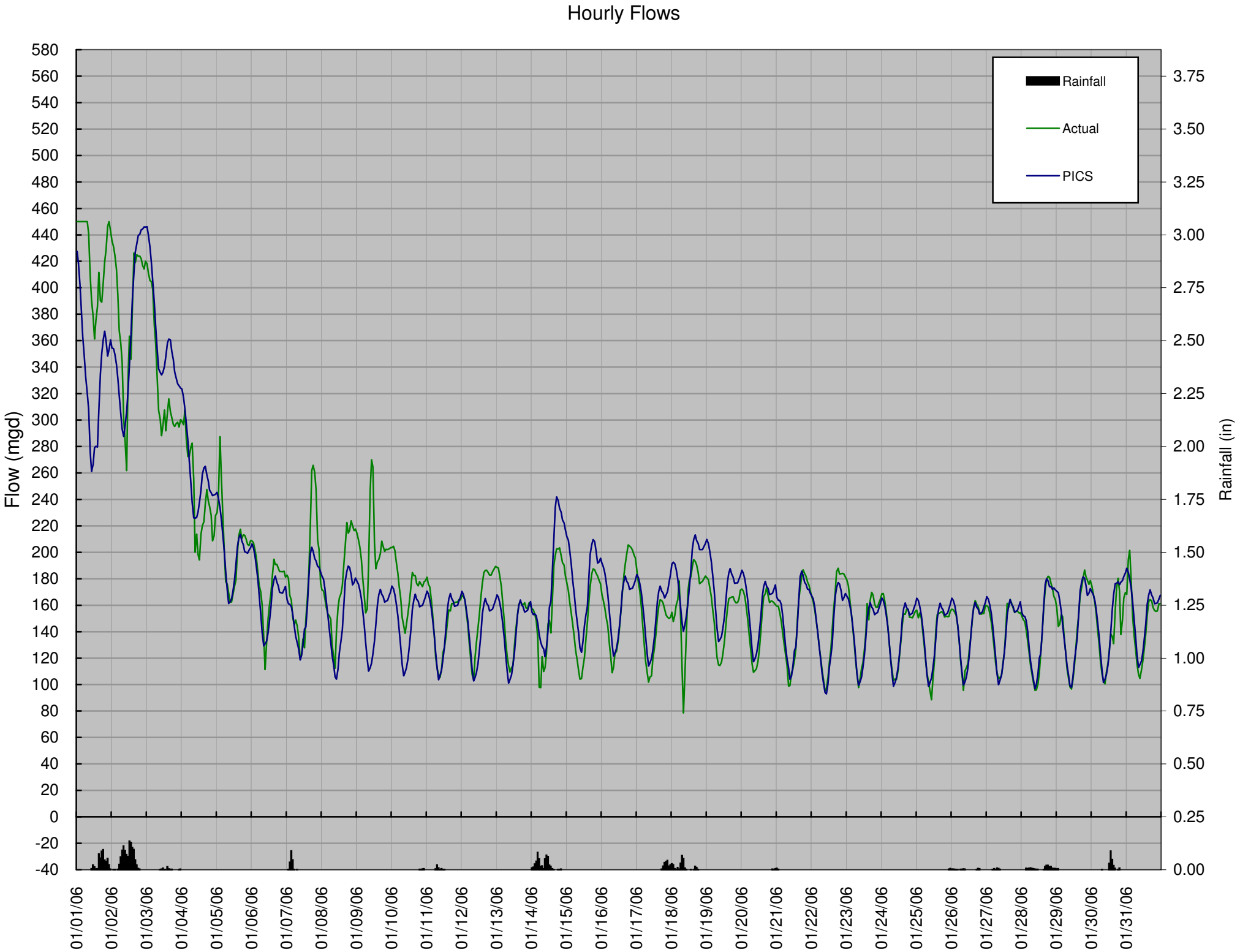
12/30/05
12/31/05


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
01/01/06
01/02/06
01/03/06
01/04/06
01/05/06
01/06/06
01/07/06
01/08/06
01/09/06
01/10/06
01/11/06
01/12/06
01/13/06
01/14/06
01/15/06
01/16/06
01/17/06
01/18/06
01/19/06
01/20/06
01/21/06
01/22/06
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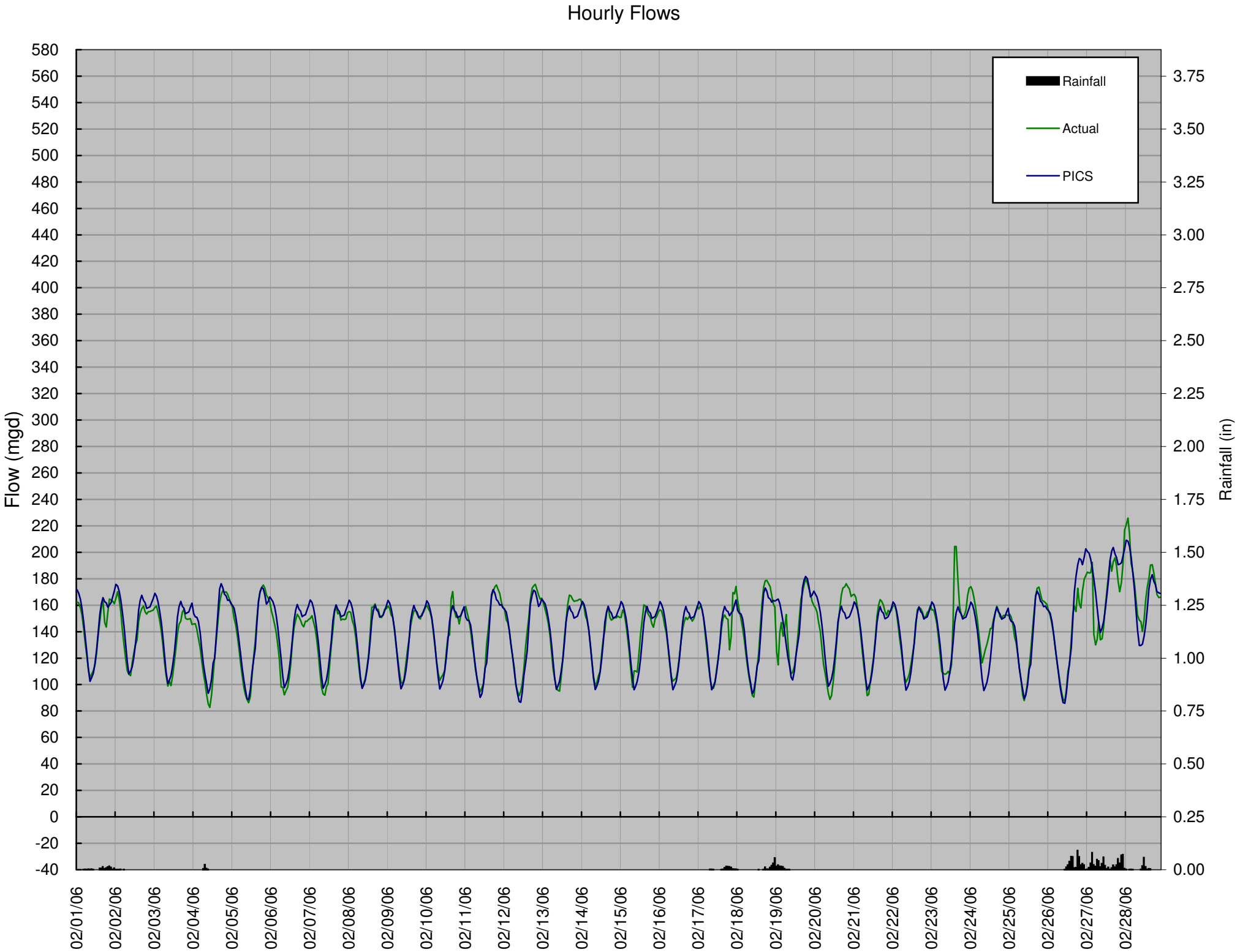
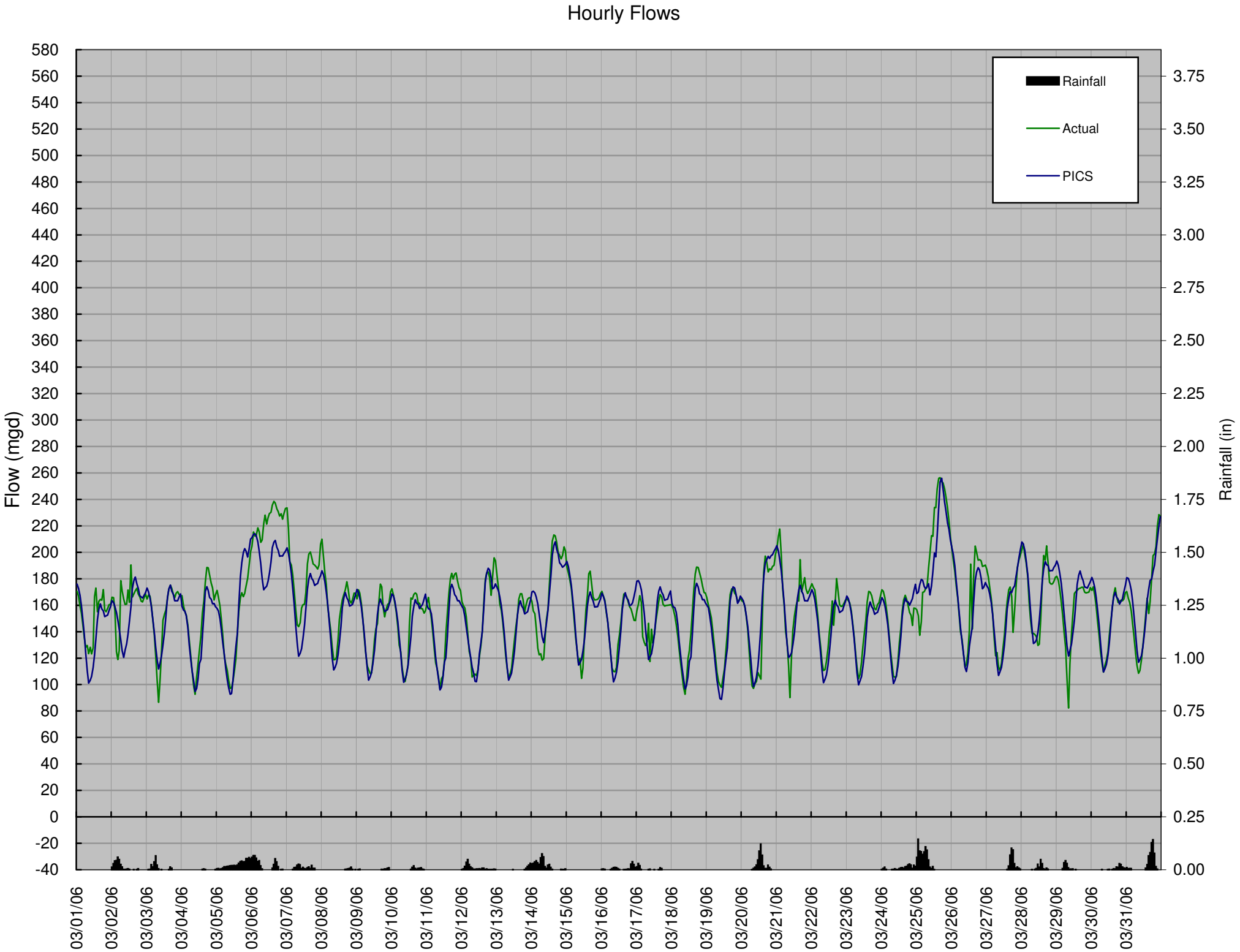
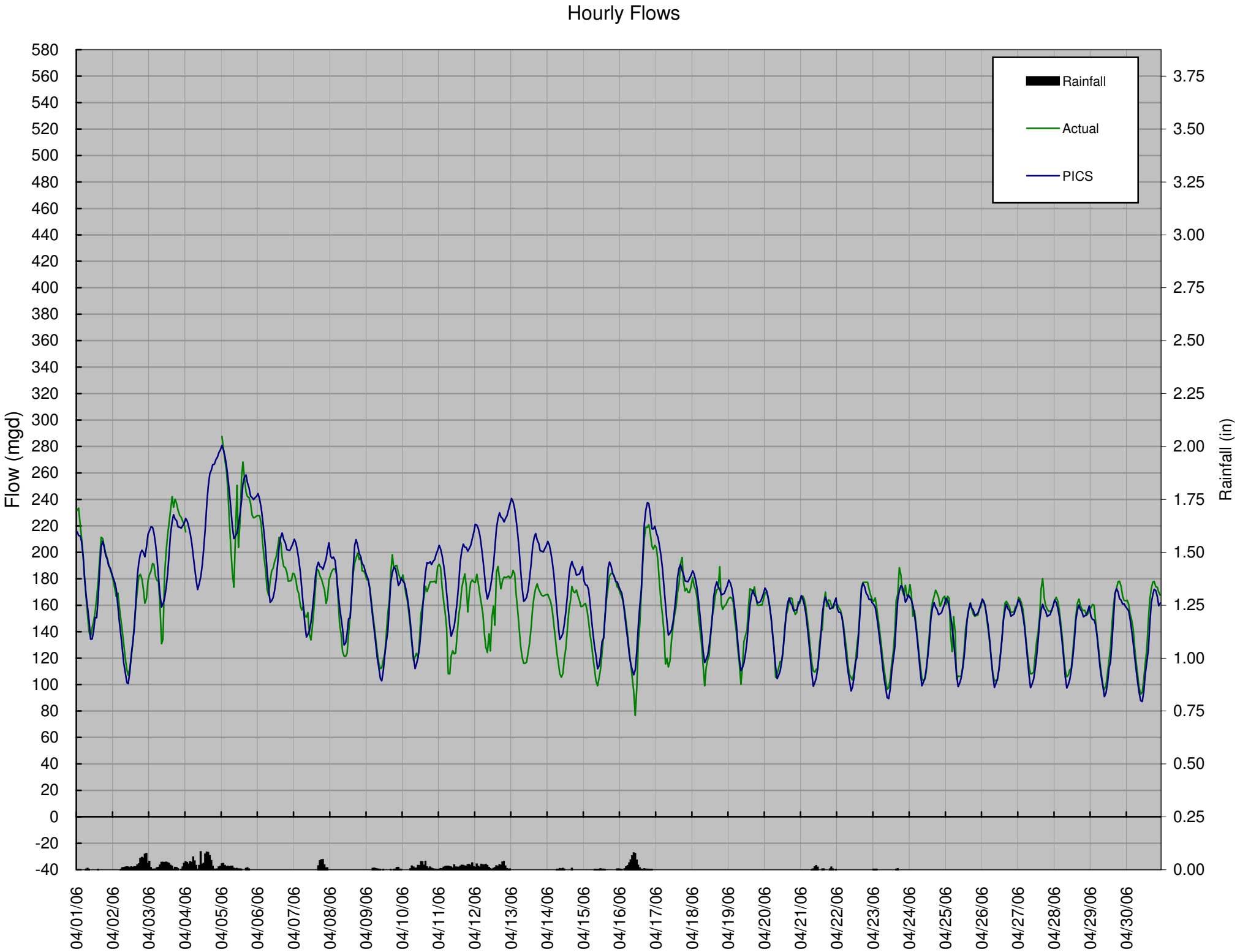
01/30/06
01/31/06


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
02/01/06
02/02/06
02/03/06
02/04/06
02/05/06
02/06/06
02/07/06
02/08/06
02/09/06
02/10/06
02/11/06
02/12/06
02/13/06
02/14/06
02/15/06
02/16/06
02/17/06
02/18/06
02/19/06
02/20/06
02/21/06
02/22/06
02/23/06
02/24/06
02/25/06
02/26/06
02/27/06
02/28/06


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
03/01/06
03/02/06
03/03/06
03/04/06
03/05/06
03/06/06
03/07/06
03/08/06
03/09/06
03/10/06
03/11/06
03/12/06
03/13/06
03/14/06
03/15/06
03/16/06
03/17/06
03/18/06
03/19/06
03/20/06
03/21/06
03/22/06
03/23/06
03/24/06
03/25/06
03/26/06
03/27/06
03/28/06
03/29/06
03/30/06
03/31/06


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
04/01/06
04/02/06
04/03/06
04/04/06
04/05/06
04/06/06
04/07/06
04/08/06
04/09/06
04/10/06
04/11/06
04/12/06
04/13/06
04/14/06
04/15/06
04/16/06
04/17/06
04/18/06
04/19/06
04/20/06
04/21/06
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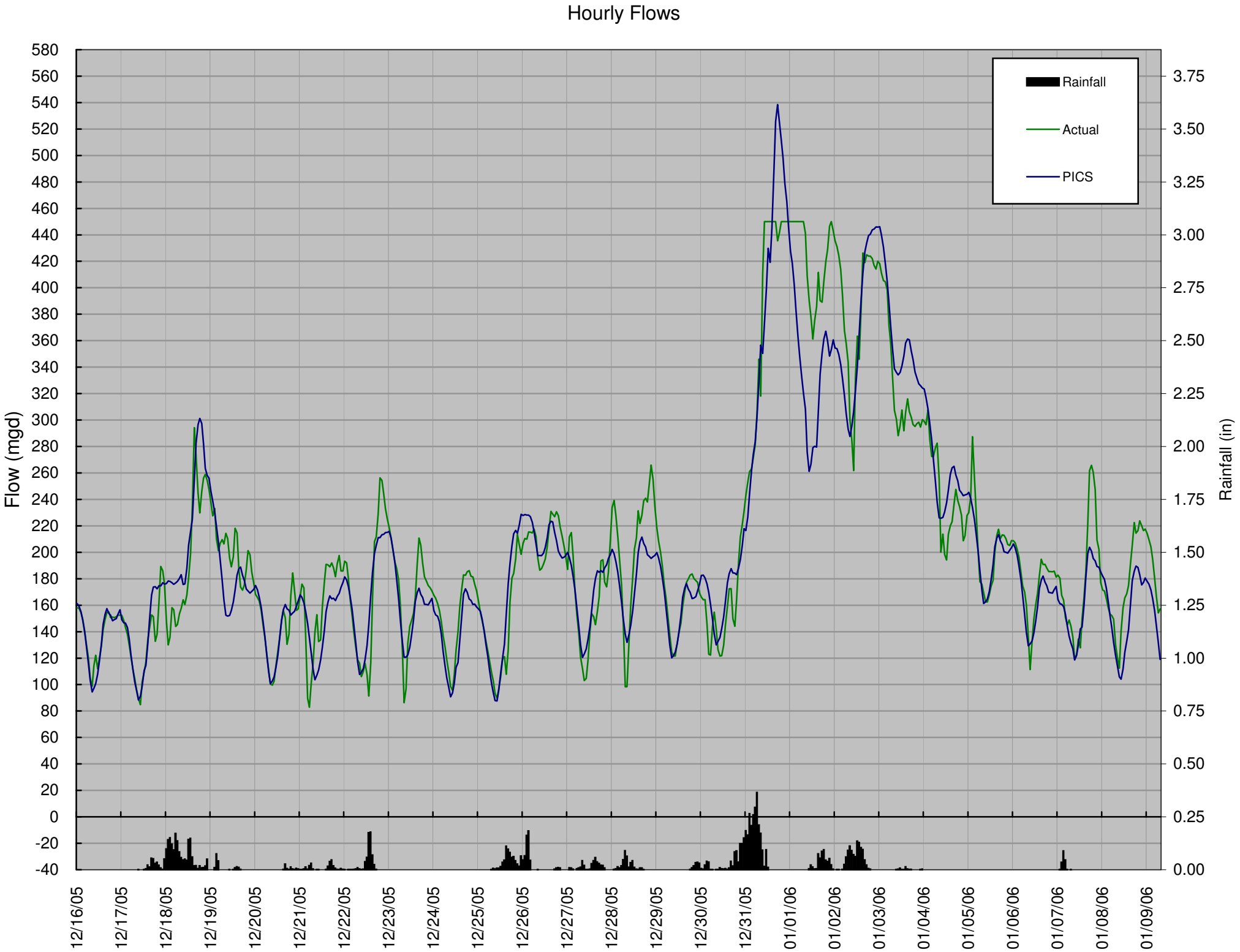
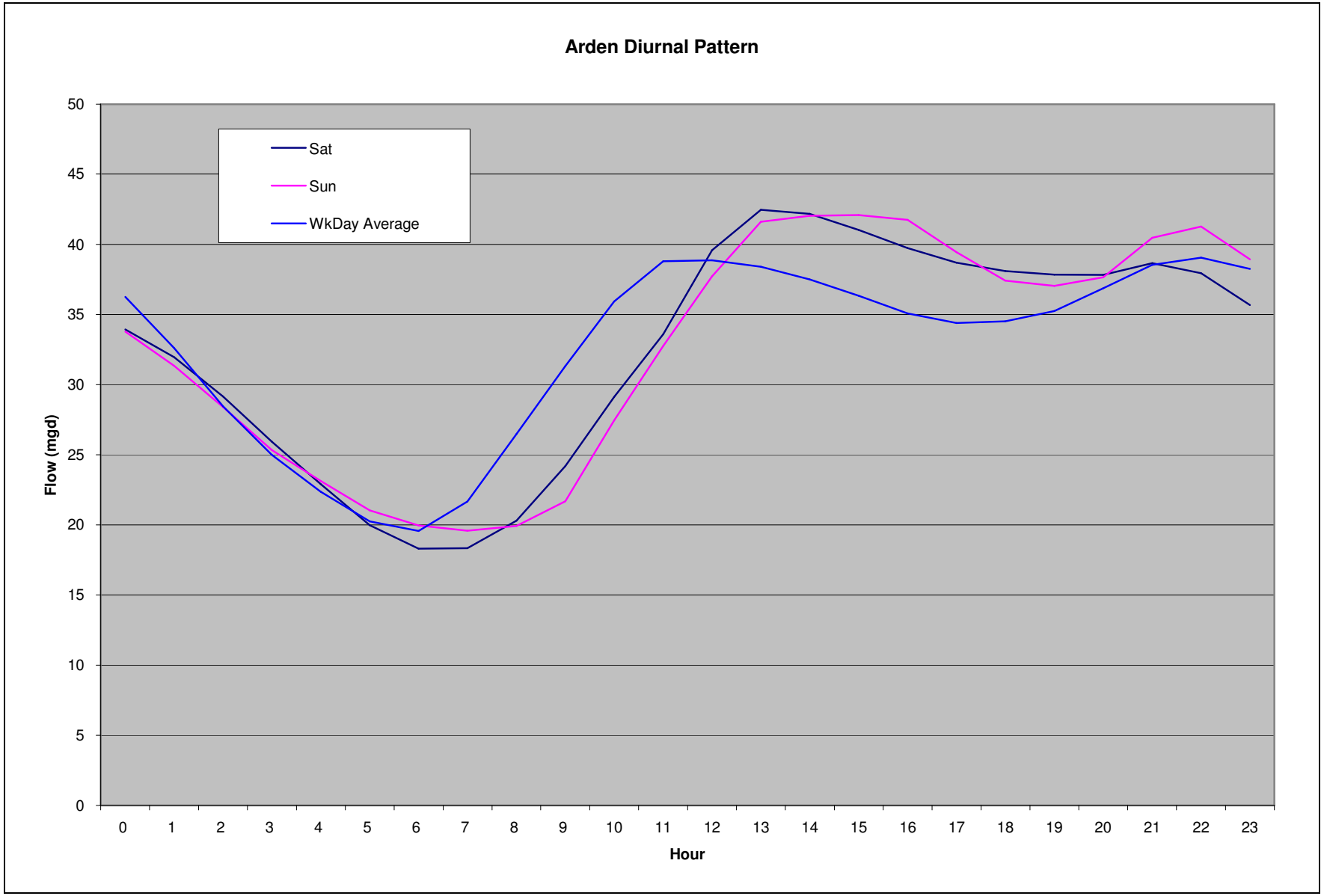
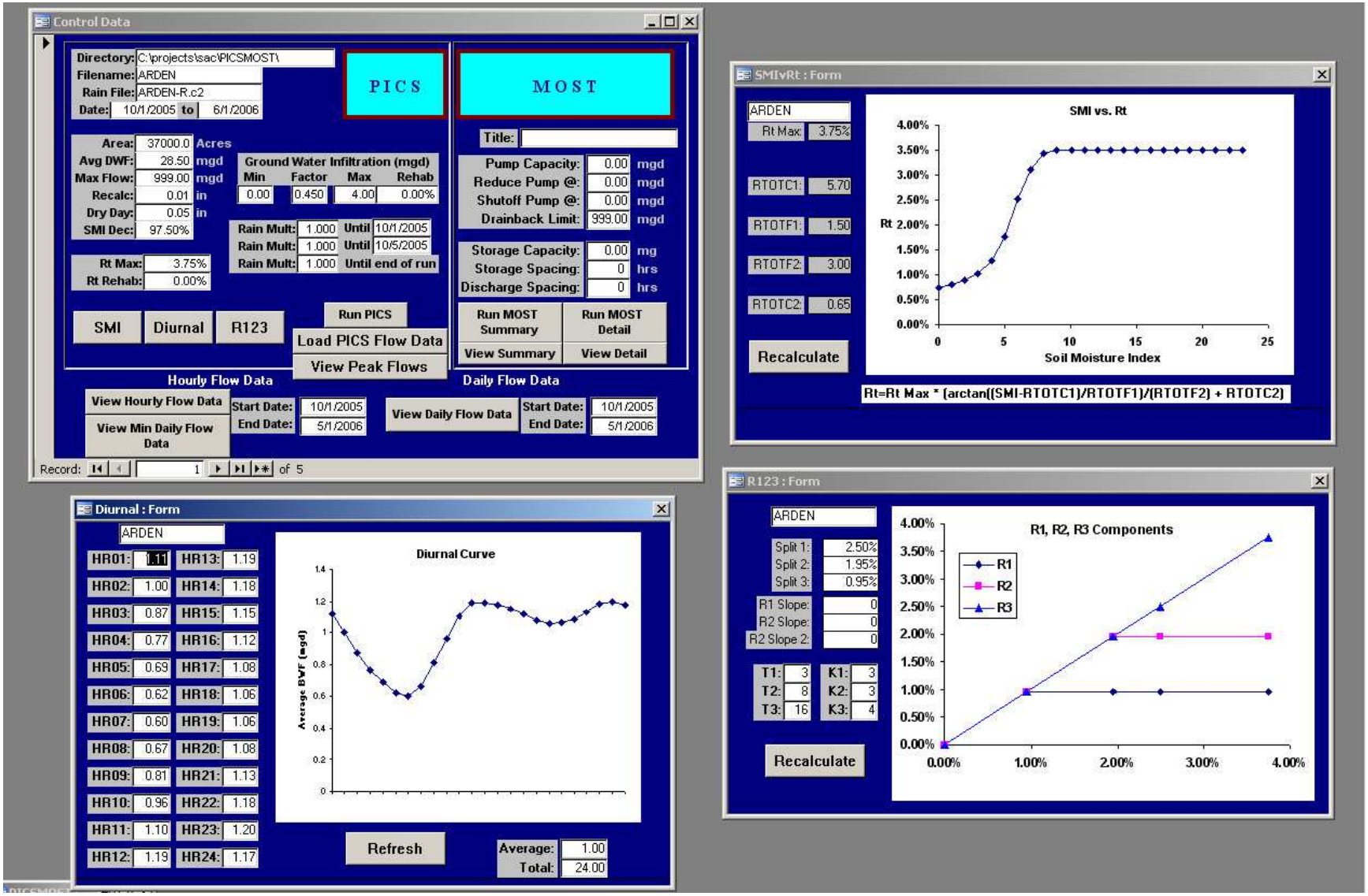
04/27/06
04/28/06
04/29/06
04/30/06

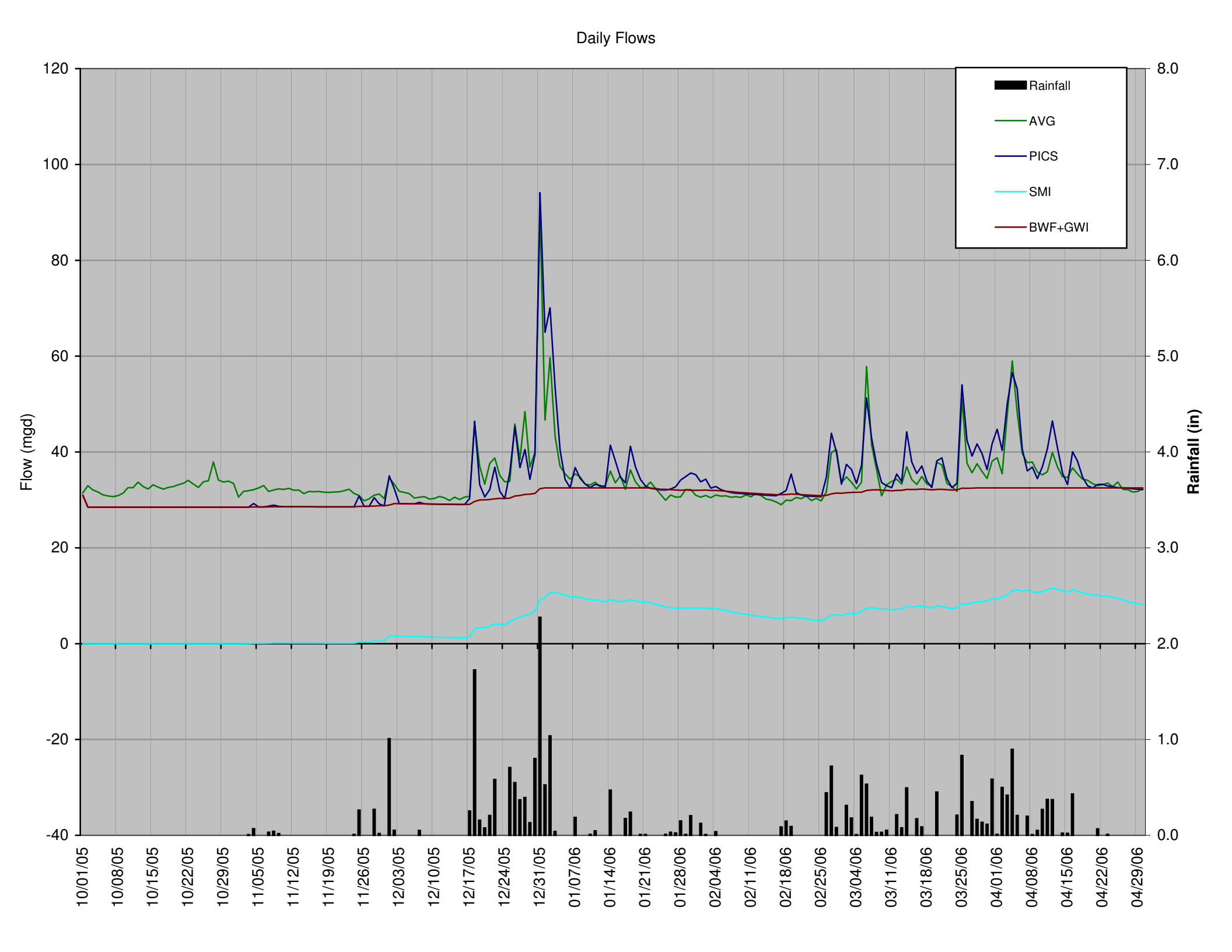

Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
12/16/05
12/17/05
12/18/05
12/19/05
12/20/05
12/21/05
12/22/05
12/23/05
12/24/05
12/25/05
12/26/05
12/27/05
12/28/05
12/29/05
12/30/05
12/31/05
01/01/06
01/02/06
01/03/06
01/04/06
01/05/06
01/06/06
01/07/06
01/08/06
01/09/06

Appendix B

CALIBRATION RESULTS FOR ARDEN SITE


Arden Diurnal Pattern
Sat
Sun
WkDay Average
Flow (mgd)
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour


Control Data
Directory: C:\projects\sac\PICSMOST\
Filename: ARDEN
Rain File: ARDEN-R.c2
Date: 10/1/2005 to 6/1/2006
PICS
MOST
Area: 37000.0 Acres
Avg DWF: 28.50 mgd
Max Flow: 999.00 mgd
Recalc: 0.01 in
Dry Day: 0.05 in
SMI Dec: 97.50%
Ground Water Infiltration (mgd)
Min Factor Max Rehab
0.00 0.450 4.00 0.00%
Rain Mult: 1.000 Until 10/1/2005
Rain Mult: 1.000 Until 10/5/2005
Rain Mult: 1.000 Until end of run
Rt Max: 3.75%
Rt Rehab: 0.00%
Title:
Pump Capacity: 0.00 mgd
Reduce Pump @: 0.00 mgd
Shutoff Pump @: 0.00 mgd
Drainback Limit: 999.00 mgd
Storage Capacity: 0.00 mg
Storage Spacing: 0 hrs
Discharge Spacing: 0 hrs
SMI
Diurnal
R123
Run PICS
Load PICS Flow Data
View Peak Flows
Run MOST Summary
Run MOST Detail
View Summary
View Detail
Hourly Flow Data
Daily Flow Data
View Hourly Flow Data
View Min Daily Flow Data
Start Date: 10/1/2005
End Date: 5/1/2006
View Daily Flow Data
Start Date: 10/1/2005
End Date: 5/1/2006
Record: 1 of 5
SMIvRt : Form
ARDEN
Rt Max: 3.75%
RTOTC1: 5.70
RTOTF1: 1.50
RTOTF2: 3.00
RTOTC2: 0.65
Recalculate
SMI vs. Rt
Rt
Soil Moisture Index
Rt=Rt Max * (arctan([SMI-RTOTC1)/RTOTF1)/(RTOTF2) + RTOTC2)
Diurnal : Form
ARDEN
HR01: 1.11
HR02: 1.00
HR03: 0.87
HR04: 0.77
HR05: 0.69
HR06: 0.62
HR07: 0.60
HR08: 0.67
HR09: 0.81
HR10: 0.96
HR11: 1.10
HR12: 1.19
HR13: 1.19
HR14: 1.18
HR15: 1.15
HR16: 1.12
HR17: 1.08
HR18: 1.06
HR19: 1.06
HR20: 1.08
HR21: 1.13
HR22: 1.18
HR23: 1.20
HR24: 1.17
Diurnal Curve
Average BWF (mgd)
Refresh
Average: 1.00
Total: 24.00
R123 : Form
ARDEN
Split 1: 2.50%
Split 2: 1.95%
Split 3: 0.95%
R1 Slope: 0
R2 Slope: 0
R2 Slope 2: 0
T1: 3
T2: 8
T3: 16
K1: 3
K2: 3
K3: 4
Recalculate
R1, R2, R3 Components
R1
R2
R3


Daily Flows
Rainfall
AVG
PICS
SMI
BWF+GWI
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
-40
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
10/01/05
10/08/05
10/15/05
10/22/05
10/29/05
11/05/05
11/12/05
11/19/05
11/26/05
12/03/05
12/10/05
12/17/05
12/24/05
12/31/05
01/07/06
01/14/06
01/21/06
01/28/06
02/04/06
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02/18/06
02/25/06
03/04/06
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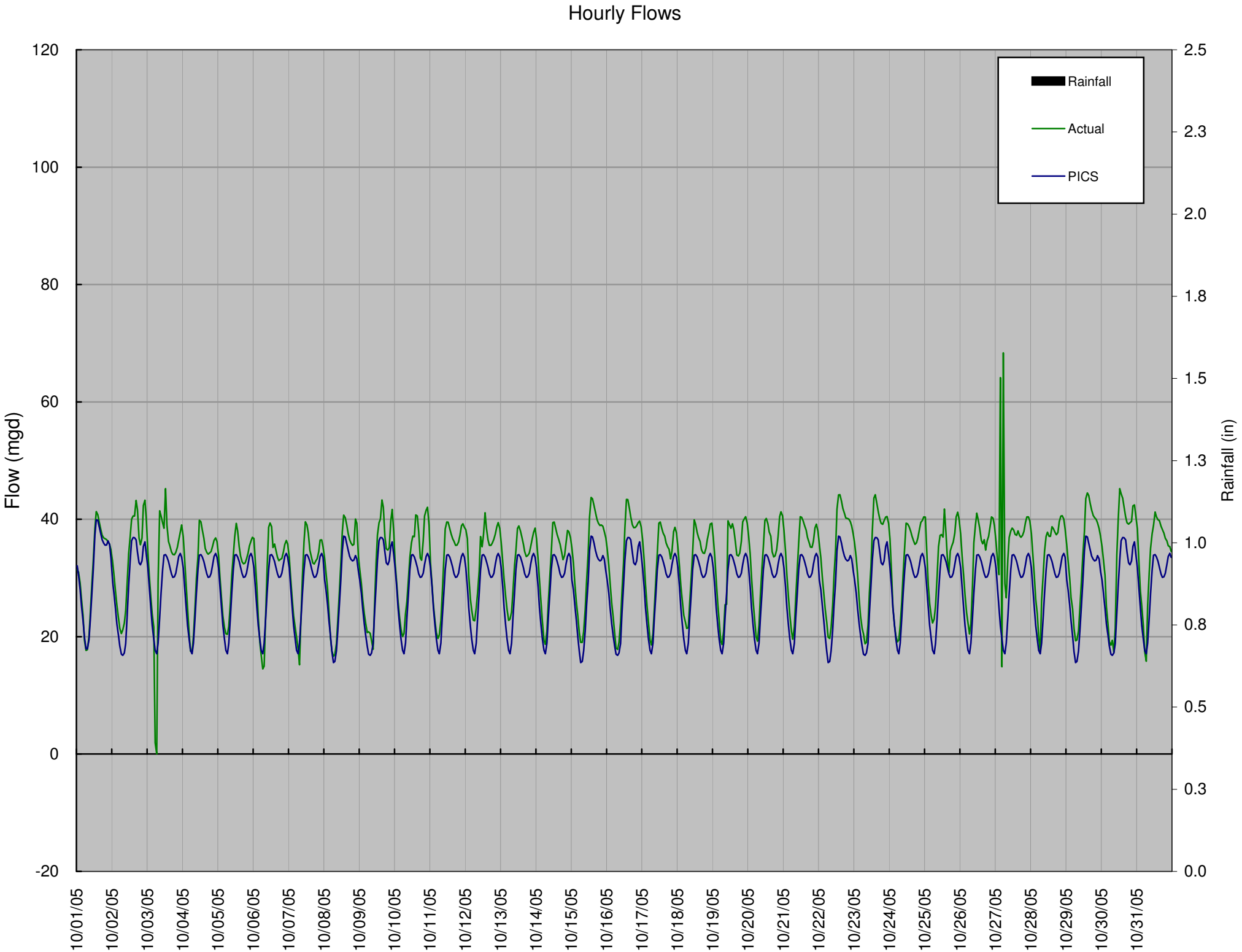
Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
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10/01/05
10/02/05
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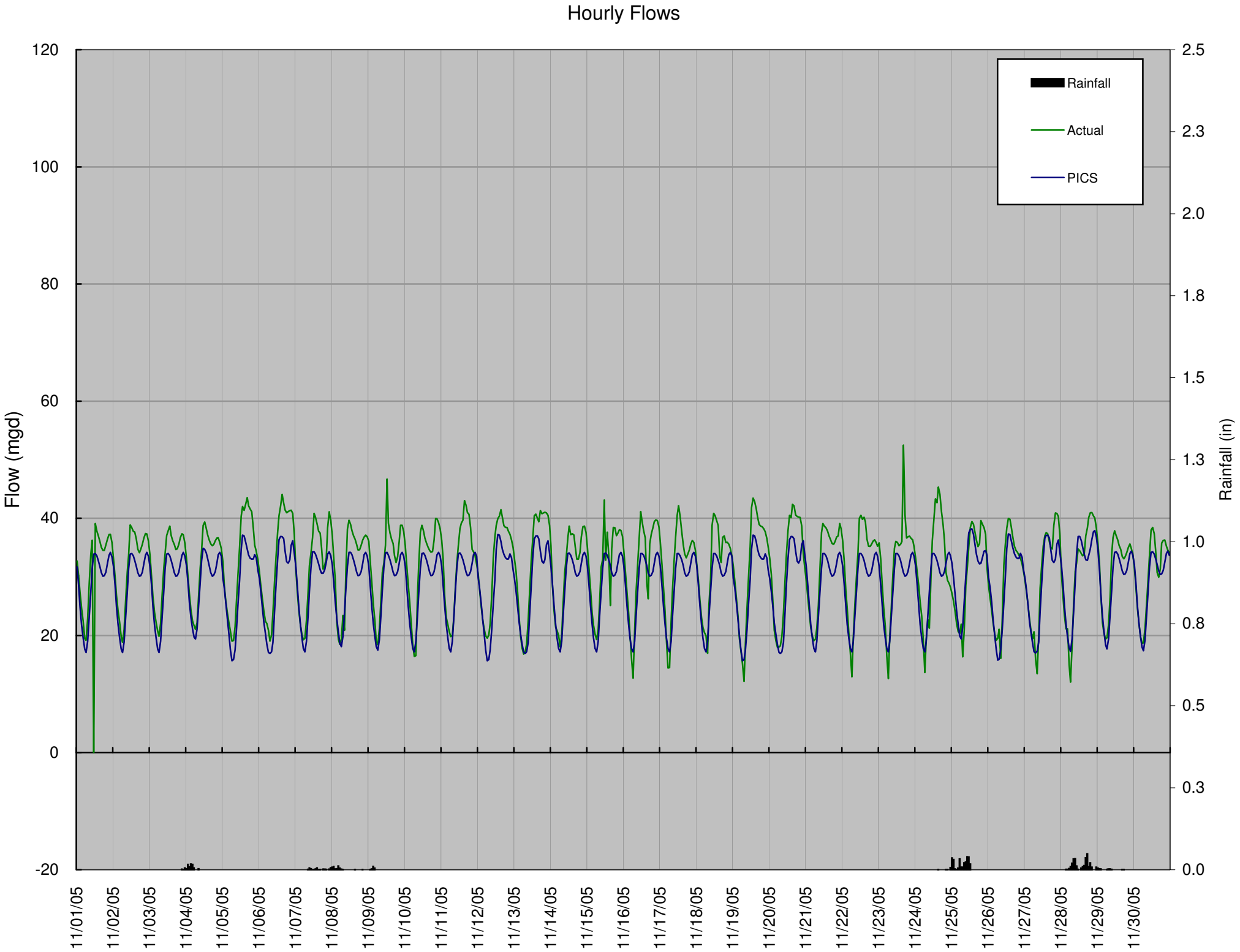
Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
2.5
2.3
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1.8
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11/01/05
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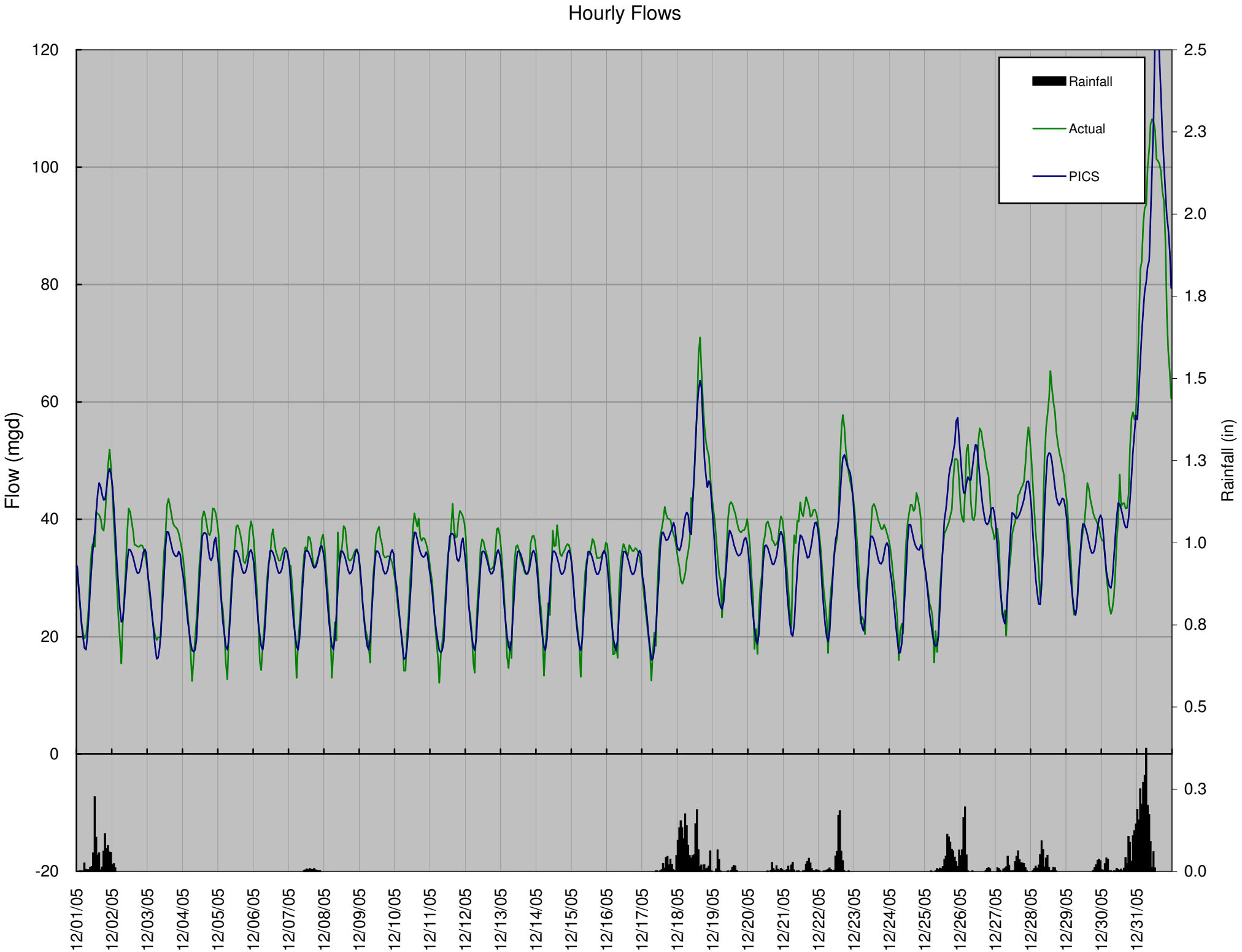
Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
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-20
2.5
2.3
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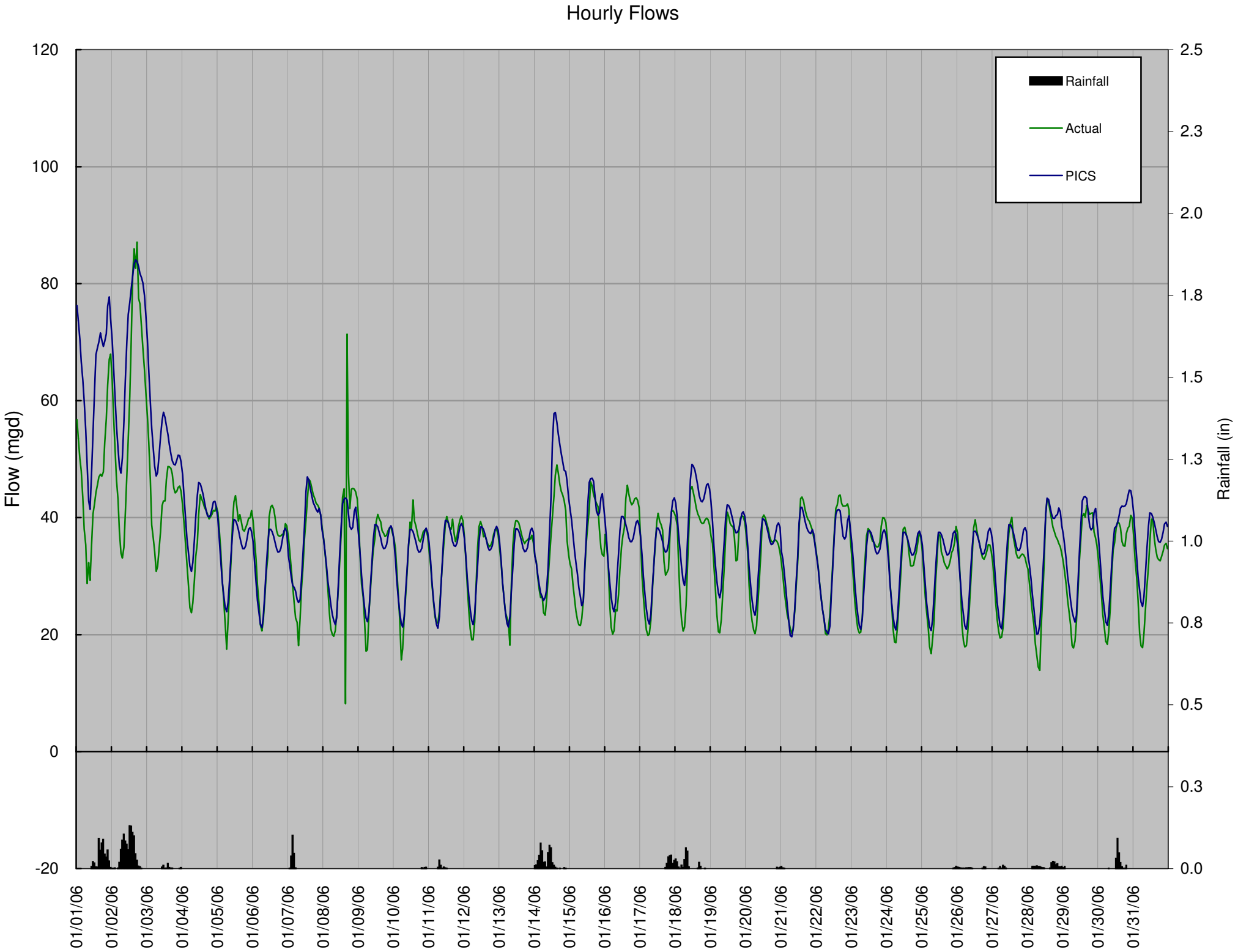
Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
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-20
2.5
2.3
2.0
1.8
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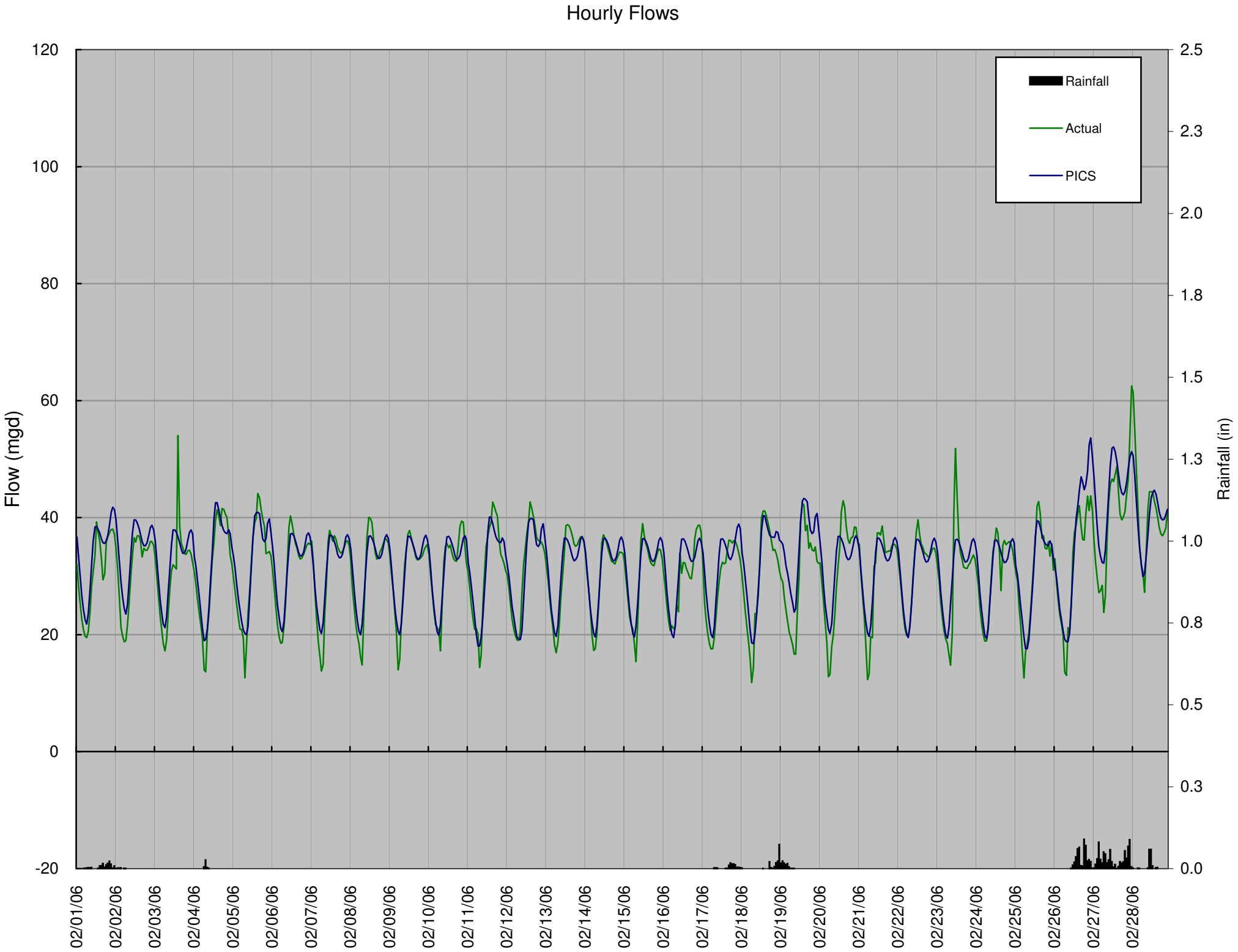
01/31/06


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
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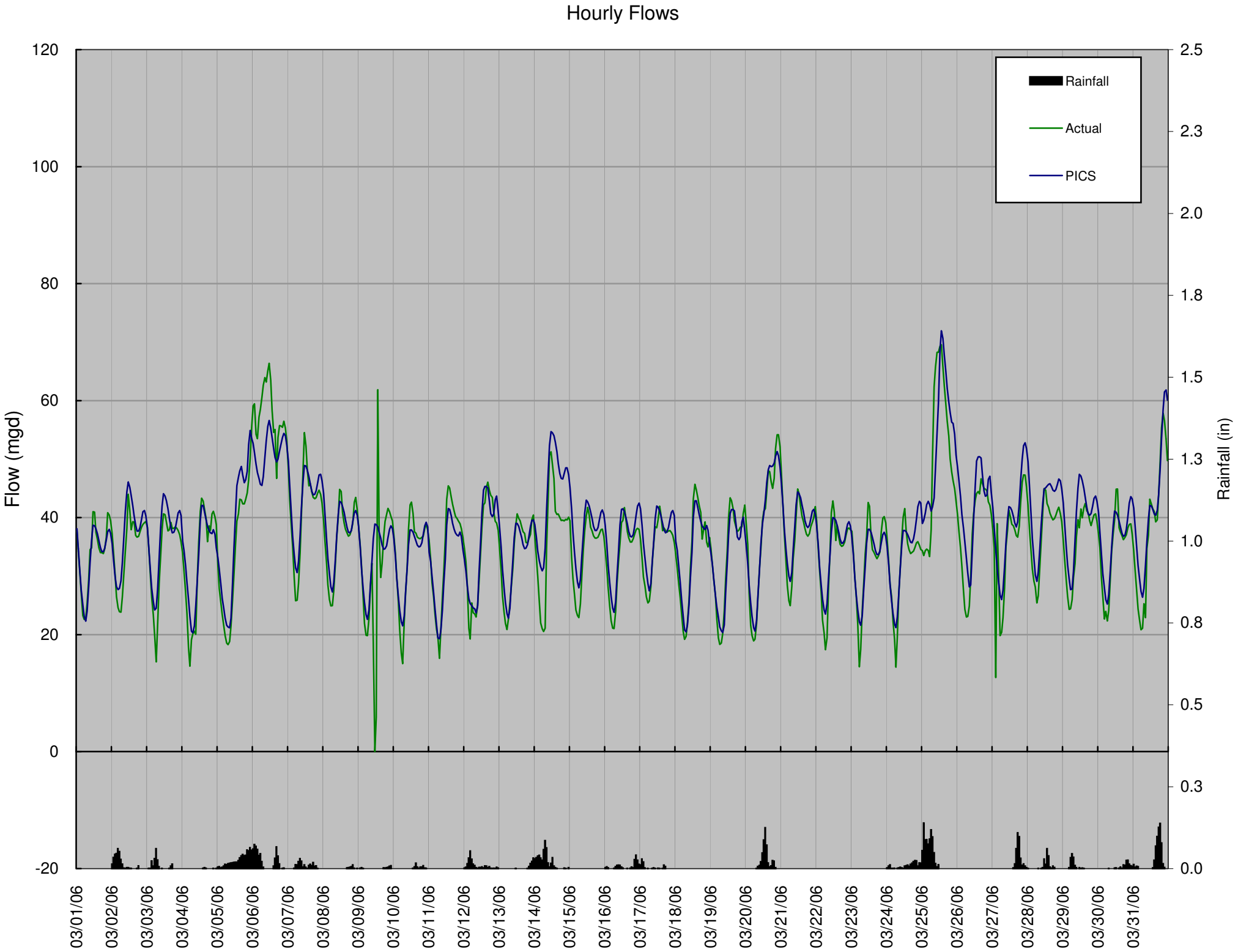
02/28/06


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
03/01/06
03/02/06
03/03/06
03/04/06
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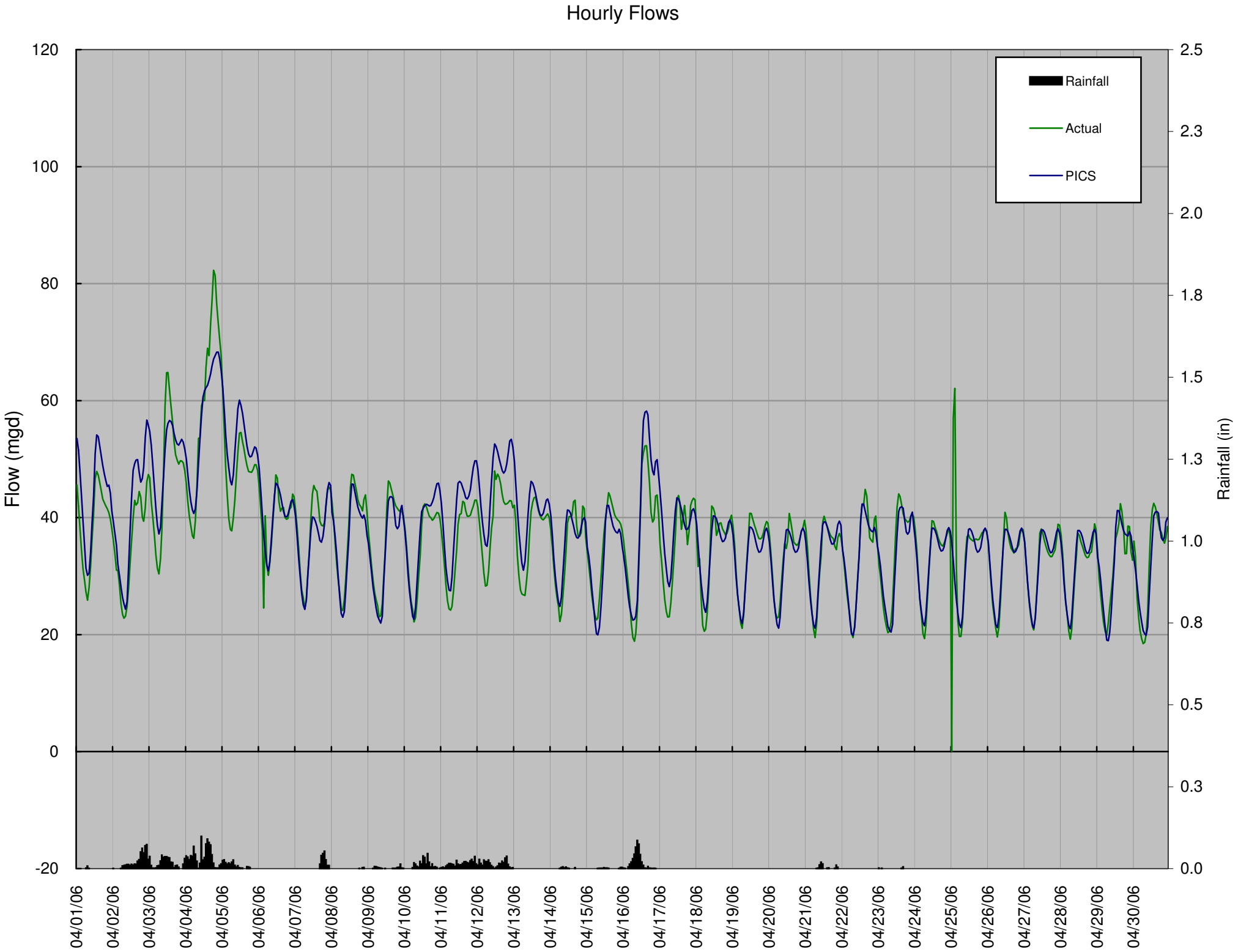
Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
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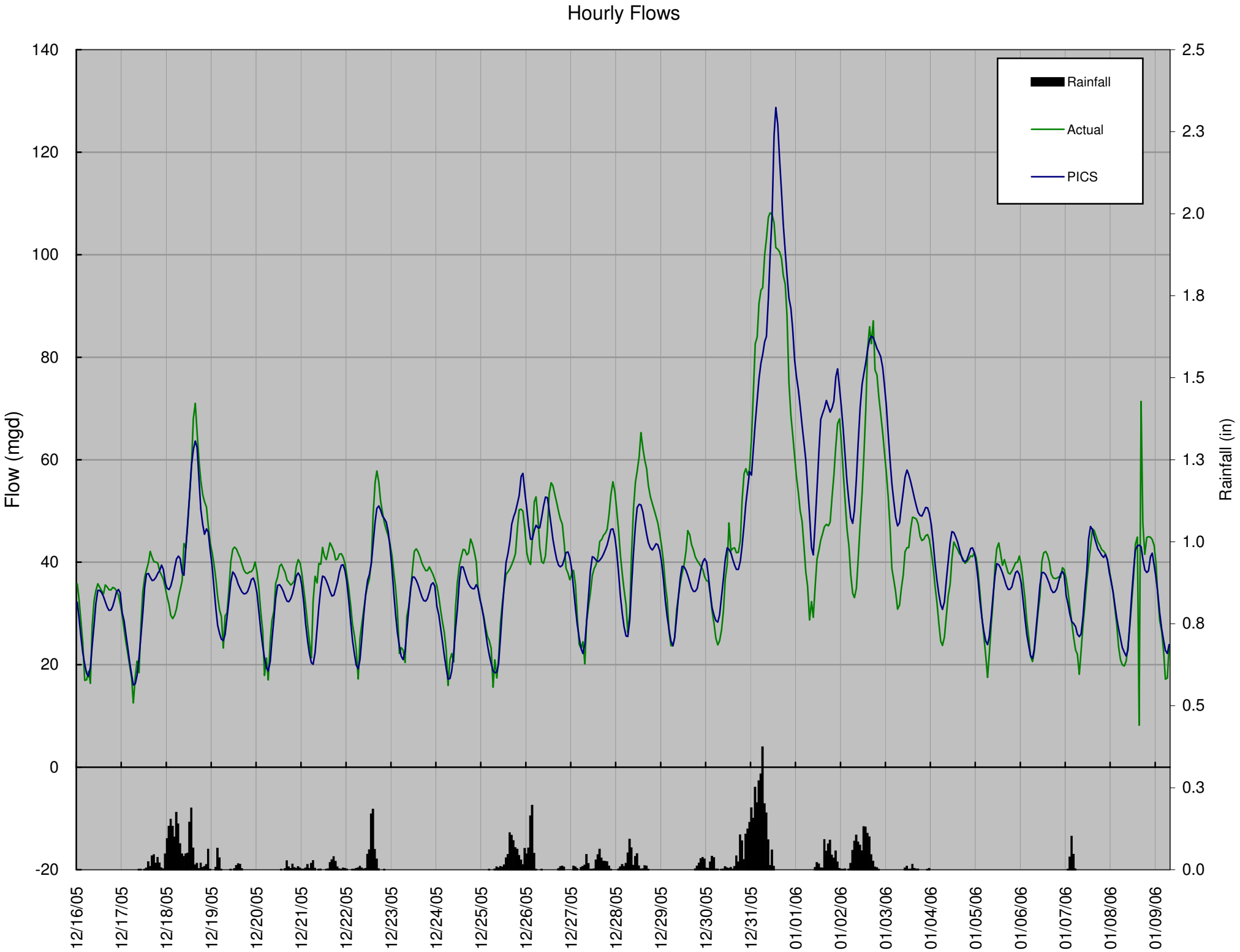
Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
140
120
100
80
60
40
20
0
-20
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
12/16/05
12/17/05
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01/01/06
01/02/06
01/03/06
01/04/06
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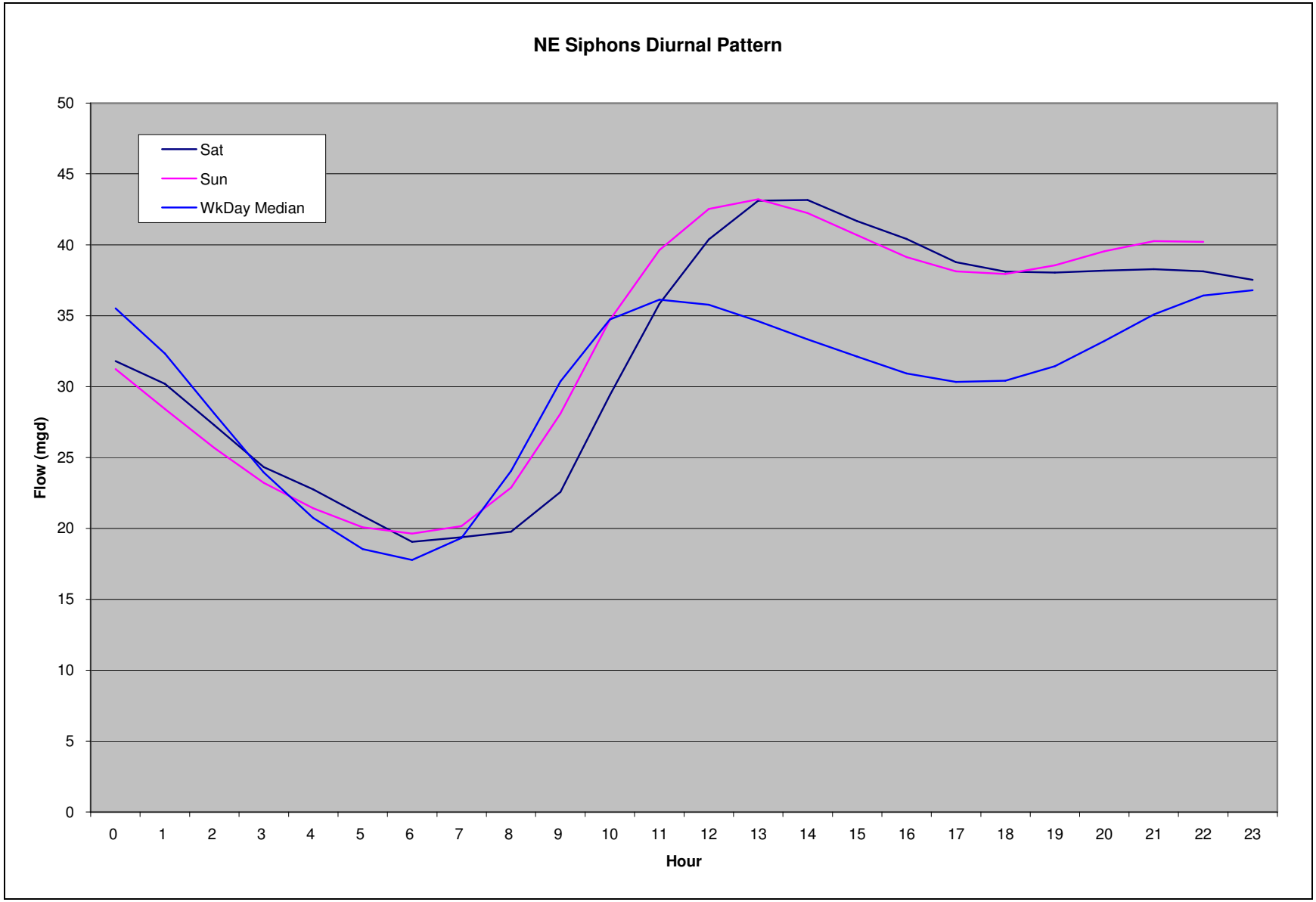
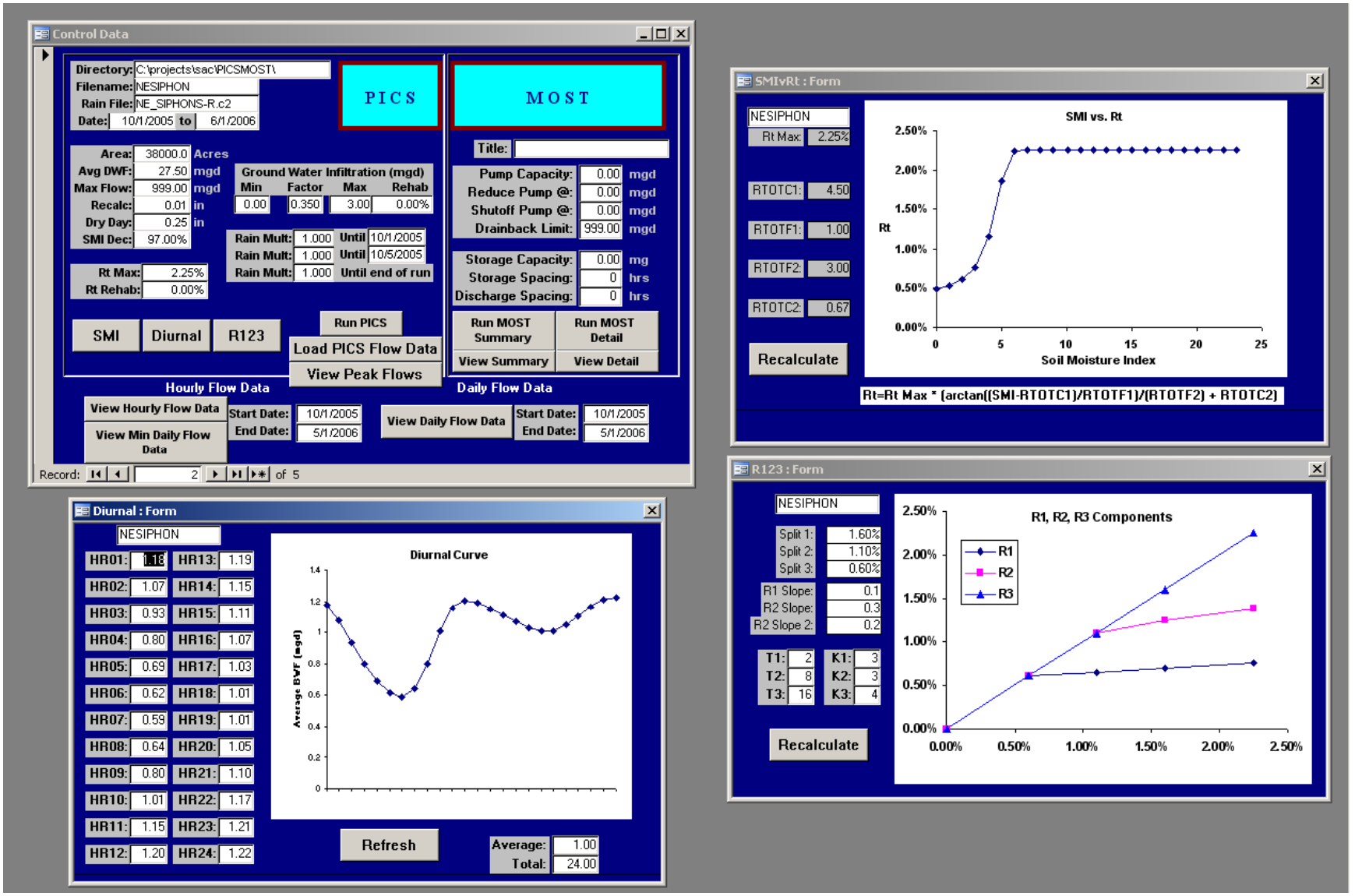
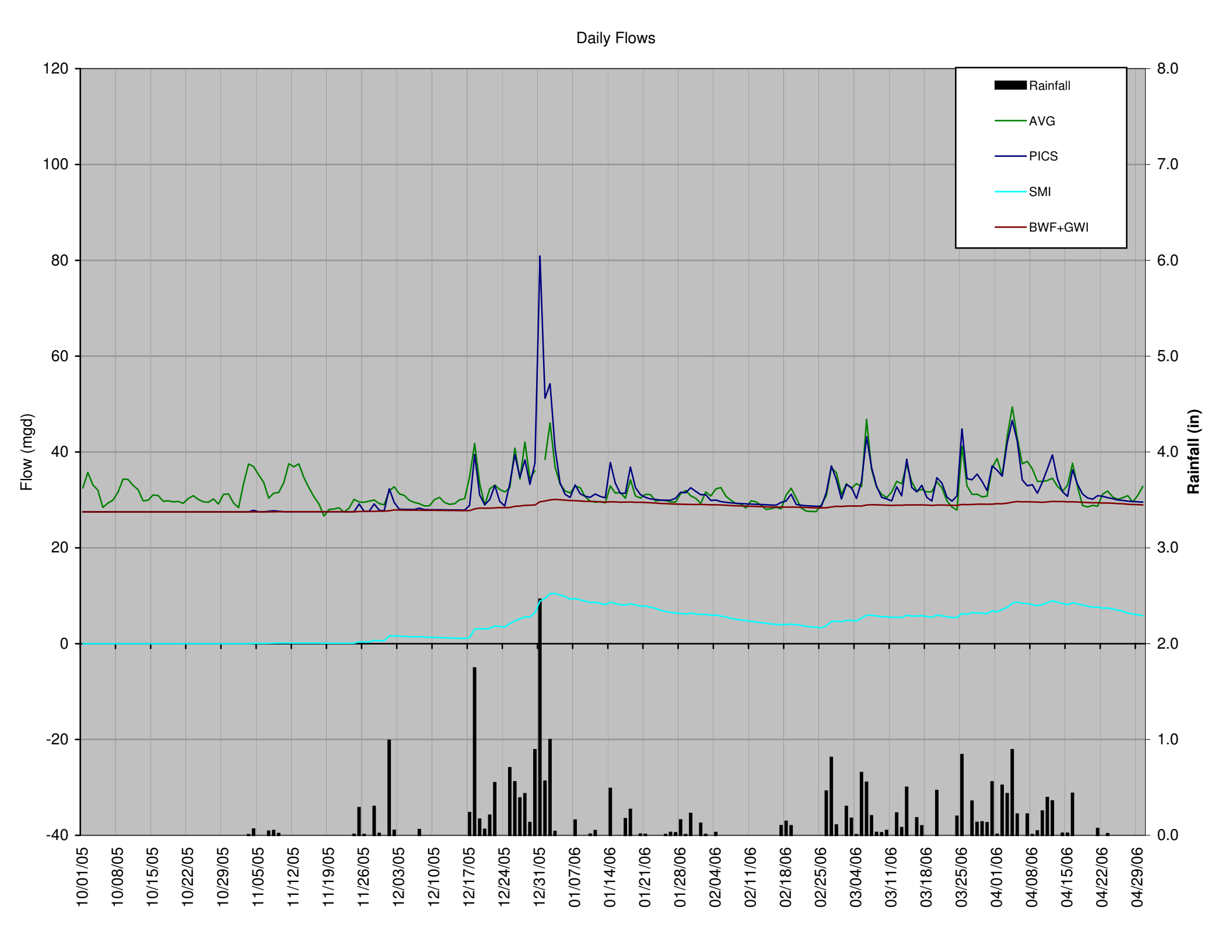
01/08/06
01/09/06

Appendix C

CALIBRATION RESULTS FOR NE SIPHONS SITE


NE Siphons Diurnal Pattern
Sat
Sun
WkDay Median
Flow (mgd)
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour


Control Data
Directory: C:\projects\sac\PICSMOST\
Filename: NESIPHON
Rain File: NE_SIPHONS-R.c2
Date: 10/1/2005 to 6/1/2006
PICS
MOST
Area: 38000.0 Acres
Avg DWF: 27.50 mgd
Max Flow: 999.00 mgd
Recalc: 0.01 in
Dry Day: 0.25 in
SMI Dec: 97.00%
Ground Water Infiltration (mgd)
Min Factor Max Rehab
0.00 0.350 3.00 0.00%
Rain Mult: 1.000 Until 10/1/2005
Rain Mult: 1.000 Until 10/5/2005
Rain Mult: 1.000 Until end of run
Rt Max: 2.25%
Rt Rehab: 0.00%
Title:
Pump Capacity: 0.00 mgd
Reduce Pump @: 0.00 mgd
Shutoff Pump @: 0.00 mgd
Drainback Limit: 999.00 mgd
Storage Capacity: 0.00 mg
Storage Spacing: 0 hrs
Discharge Spacing: 0 hrs
SMI
Diurnal
R123
Run PICS
Load PICS Flow Data
View Peak Flows
Run MOST Summary
Run MOST Detail
View Summary
View Detail
Hourly Flow Data
Daily Flow Data
View Hourly Flow Data
View Min Daily Flow Data
Start Date: 10/1/2005
End Date: 5/1/2006
View Daily Flow Data
Start Date: 10/1/2005
End Date: 5/1/2006
Record: 2 of 5
SMIvRt : Form
NESIPHON
Rt Max: 2.25%
RTOTC1: 4.50
RTOTF1: 1.00
RTOTF2: 3.00
RTOTC2: 0.67
Recalculate
SMI vs. Rt
Rt
Soil Moisture Index
Rt=Rt Max * (arctan([SMI-RTOTC1)/RTOTF1)/(RTOTF2) + RTOTC2)
Diurnal : Form
NESIPHON
HR01: 1.18
HR02: 1.07
HR03: 0.93
HR04: 0.80
HR05: 0.69
HR06: 0.62
HR07: 0.59
HR08: 0.64
HR09: 0.80
HR10: 1.01
HR11: 1.15
HR12: 1.20
HR13: 1.19
HR14: 1.15
HR15: 1.11
HR16: 1.07
HR17: 1.03
HR18: 1.01
HR19: 1.01
HR20: 1.05
HR21: 1.10
HR22: 1.17
HR23: 1.21
HR24: 1.22
Diurnal Curve
Average BWF (mgd)
Refresh
Average: 1.00
Total: 24.00
R123 : Form
NESIPHON
Split 1: 1.60%
Split 2: 1.10%
Split 3: 0.60%
R1 Slope: 0.1
R2 Slope: 0.3
R2 Slope 2: 0.2
T1: 2
T2: 8
T3: 16
K1: 3
K2: 3
K3: 4
Recalculate
R1, R2, R3 Components
R1
R2
R3


Daily Flows
Rainfall
AVG
PICS
SMI
BWF+GWI
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
-40
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
10/01/05
10/08/05
10/15/05
10/22/05
10/29/05
11/05/05
11/12/05
11/19/05
11/26/05
12/03/05
12/10/05
12/17/05
12/24/05
12/31/05
01/07/06
01/14/06
01/21/06
01/28/06
02/04/06
02/11/06
02/18/06
02/25/06
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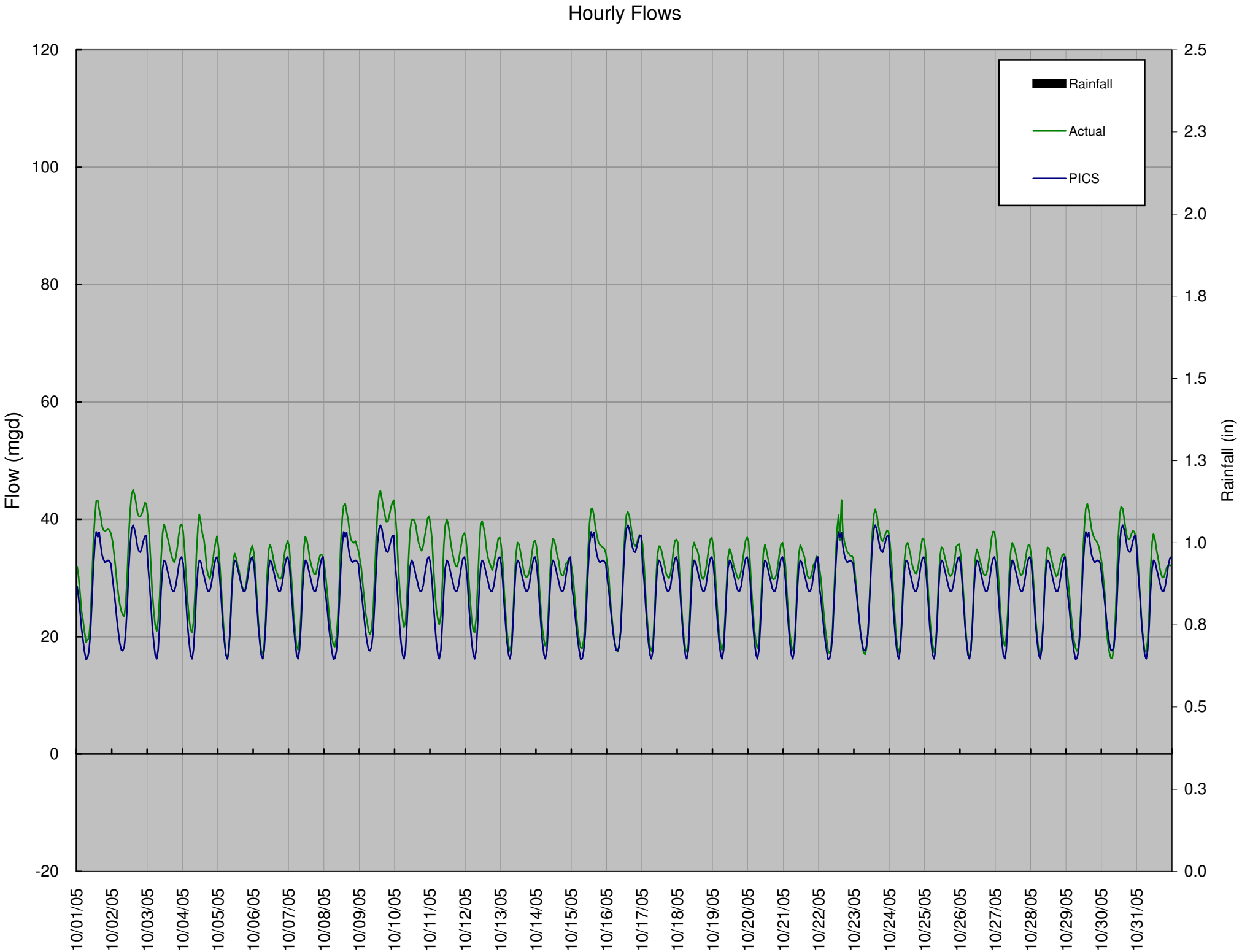
Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
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0.0
10/01/05
10/02/05
10/03/05
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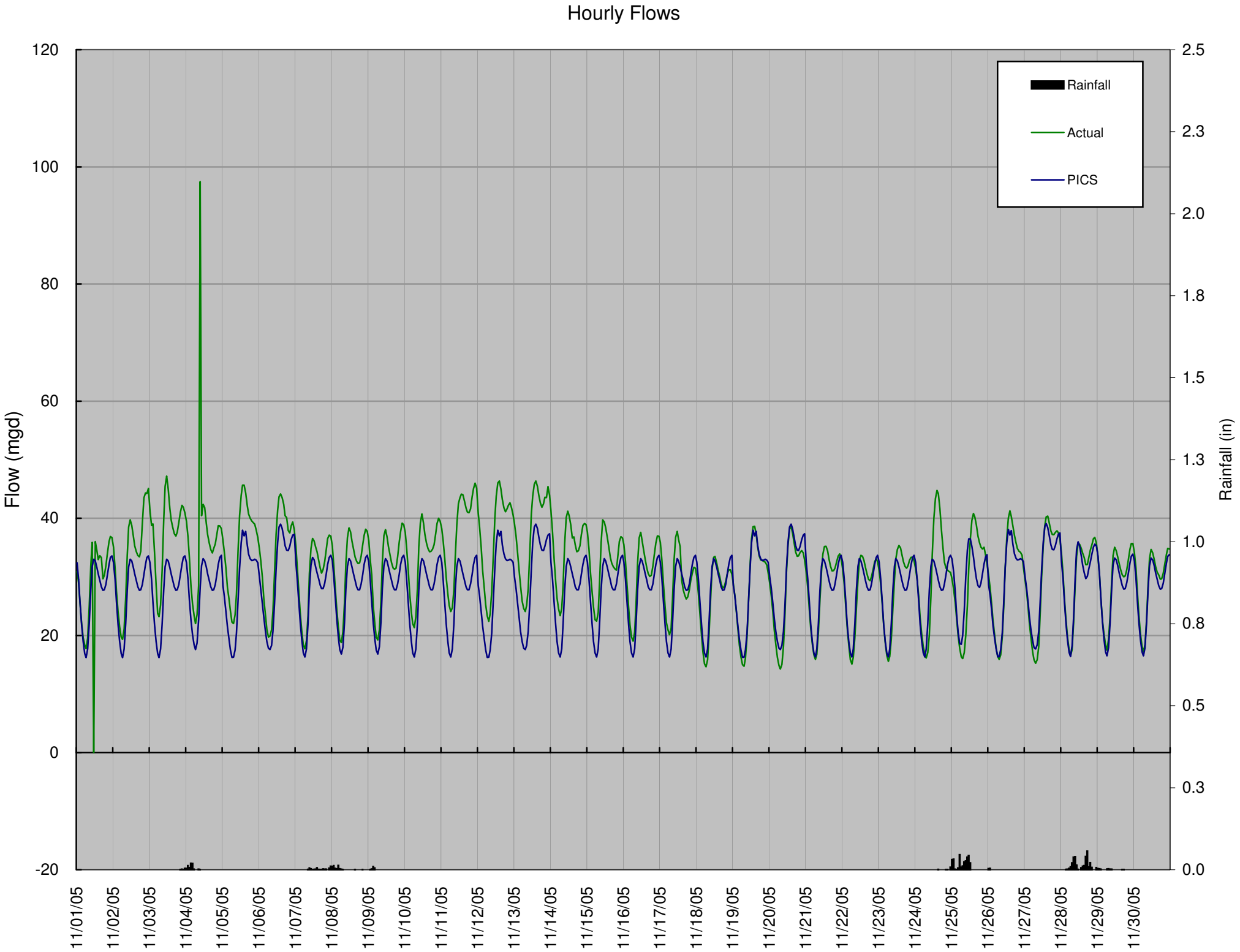
Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
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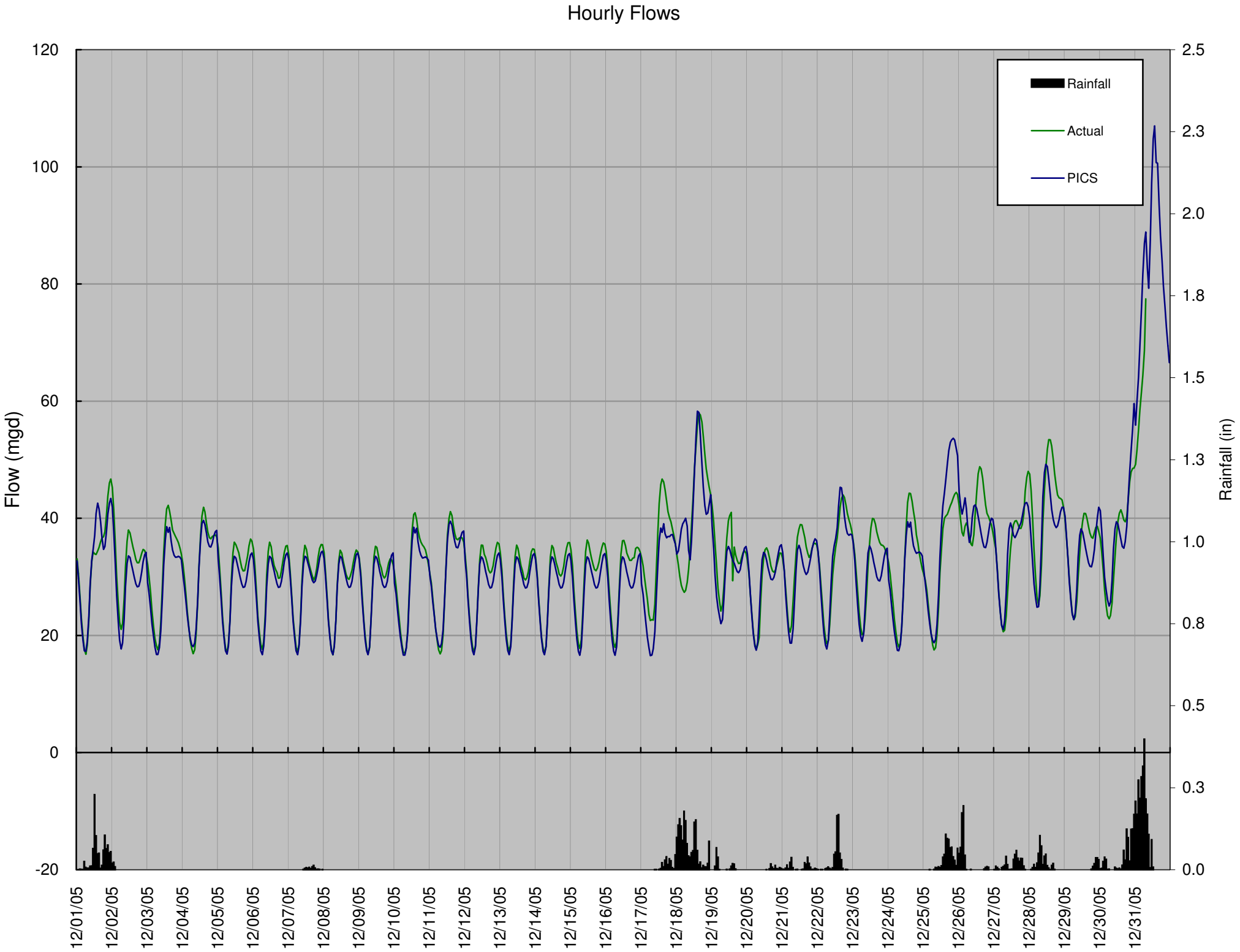
11/30/05


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
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0.8
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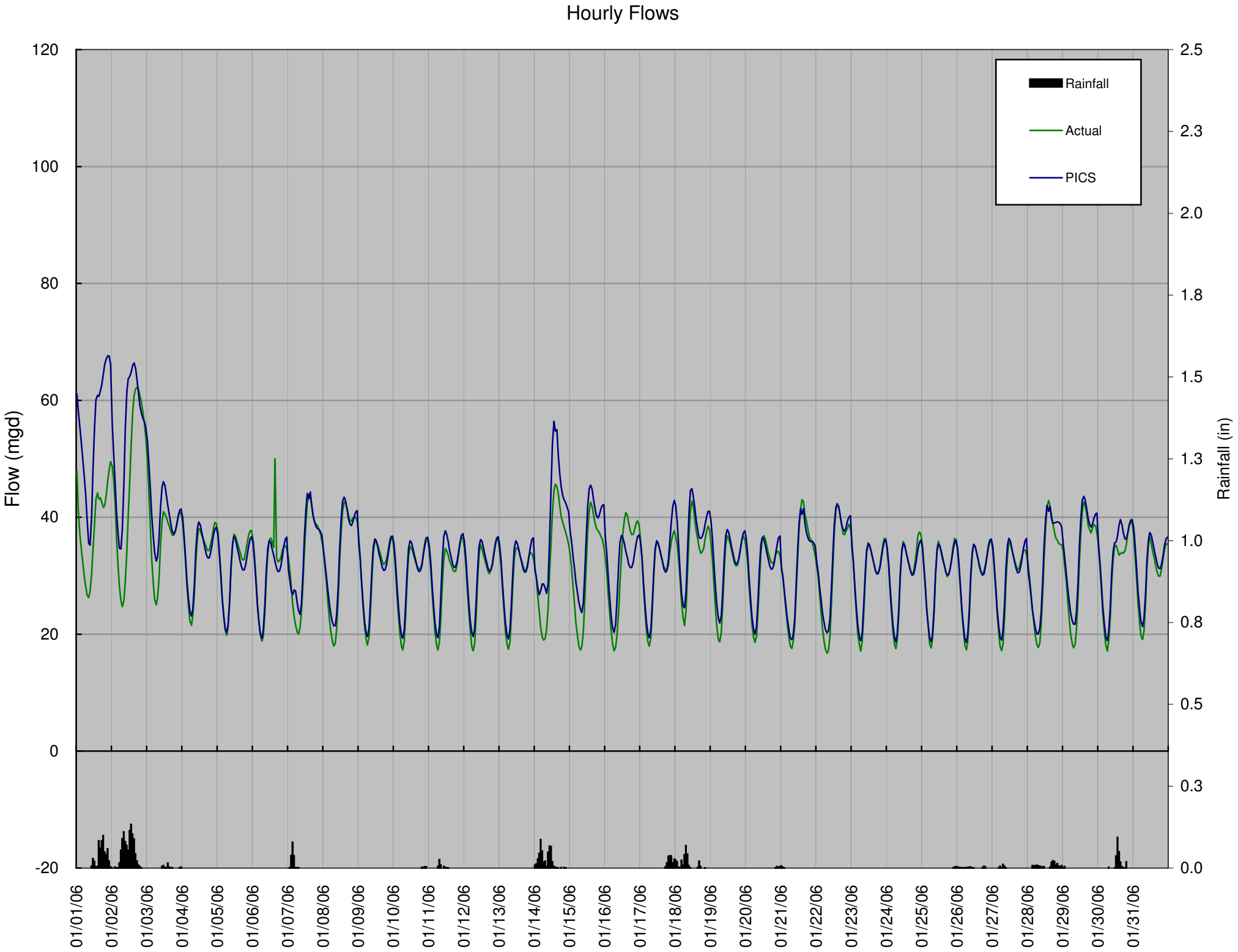
12/31/05


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
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60
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01/01/06
01/02/06
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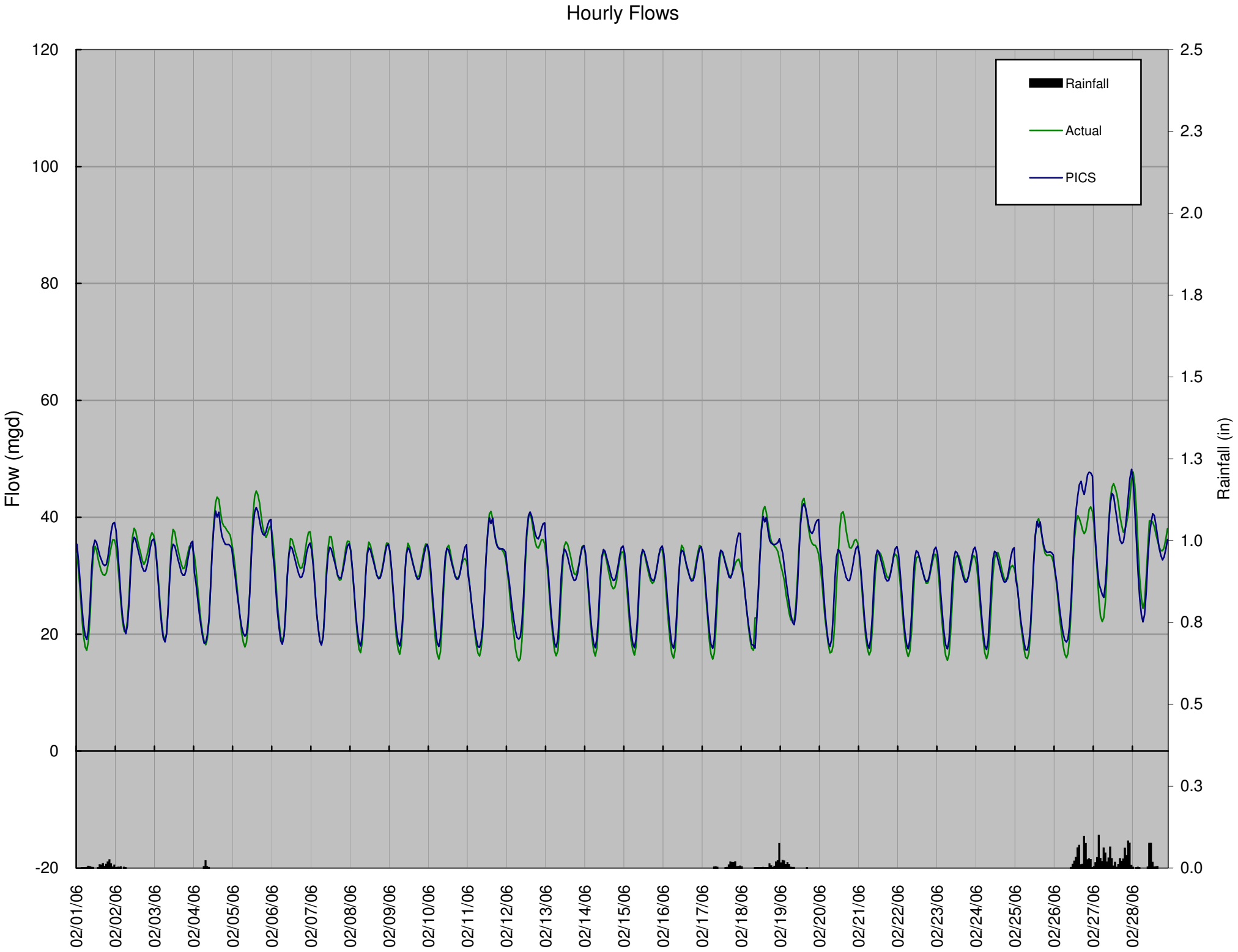
Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
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80
60
40
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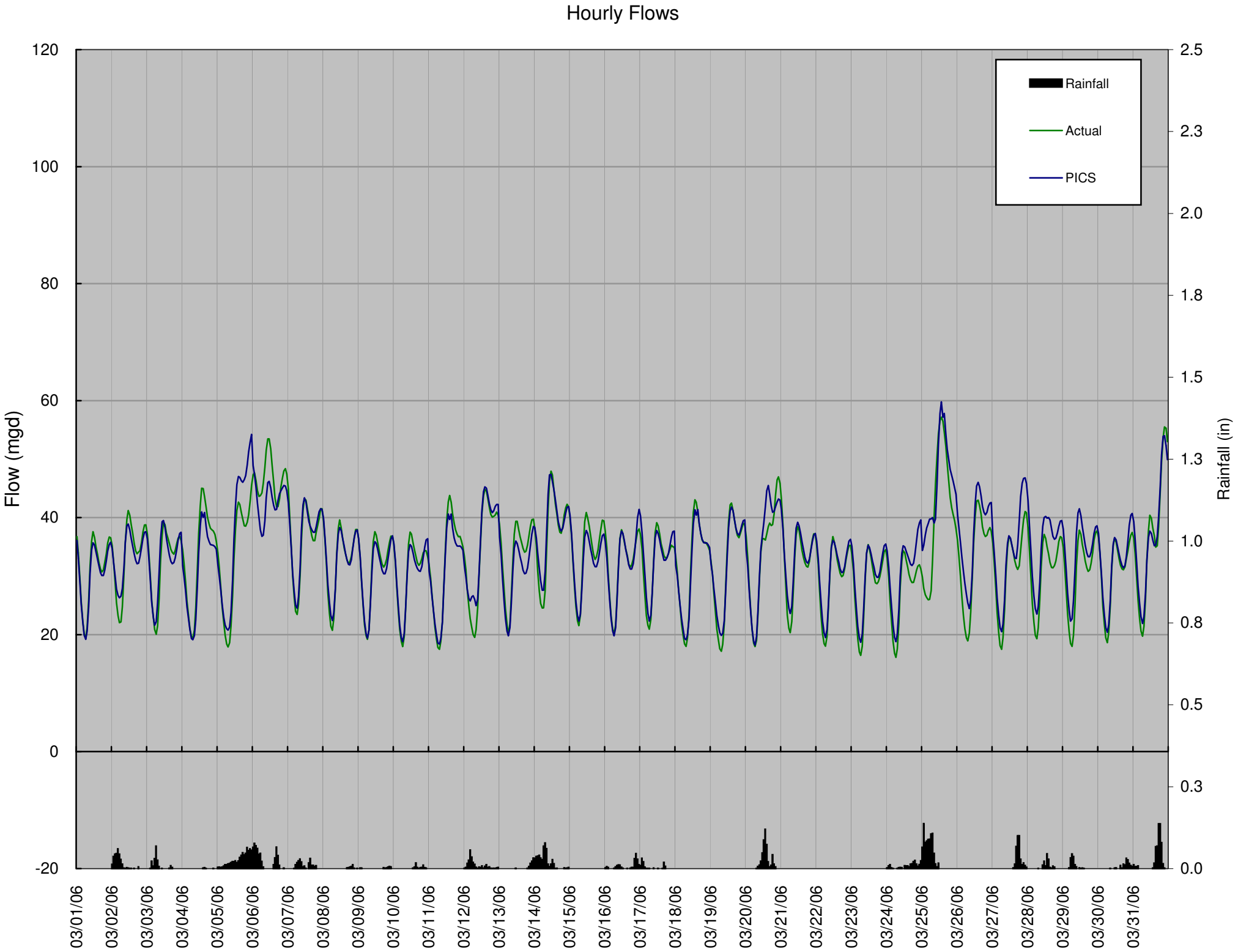
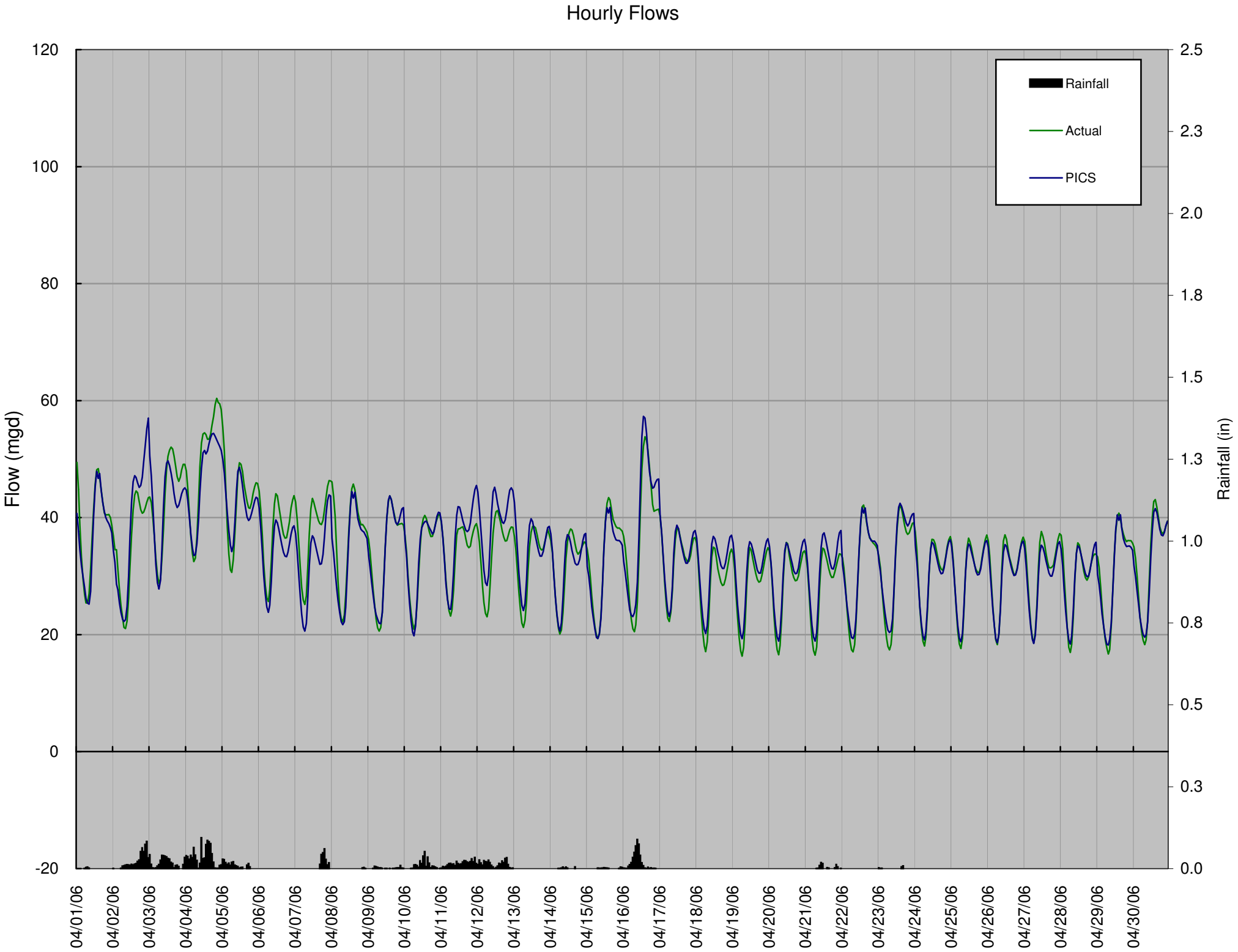
02/28/06


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
03/01/06
03/02/06
03/03/06
03/04/06
03/05/06
03/06/06
03/07/06
03/08/06
03/09/06
03/10/06
03/11/06
03/12/06
03/13/06
03/14/06
03/15/06
03/16/06
03/17/06
03/18/06
03/19/06
03/20/06
03/21/06
03/22/06
03/23/06
03/24/06
03/25/06
03/26/06
03/27/06
03/28/06
03/29/06
03/30/06
03/31/06


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
2.5
2.3
2.0
1.8
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1.3
1.0
0.8
0.5
0.3
0.0
04/01/06
04/02/06
04/03/06
04/04/06
04/05/06
04/06/06
04/07/06
04/08/06
04/09/06
04/10/06
04/11/06
04/12/06
04/13/06
04/14/06
04/15/06
04/16/06
04/17/06
04/18/06
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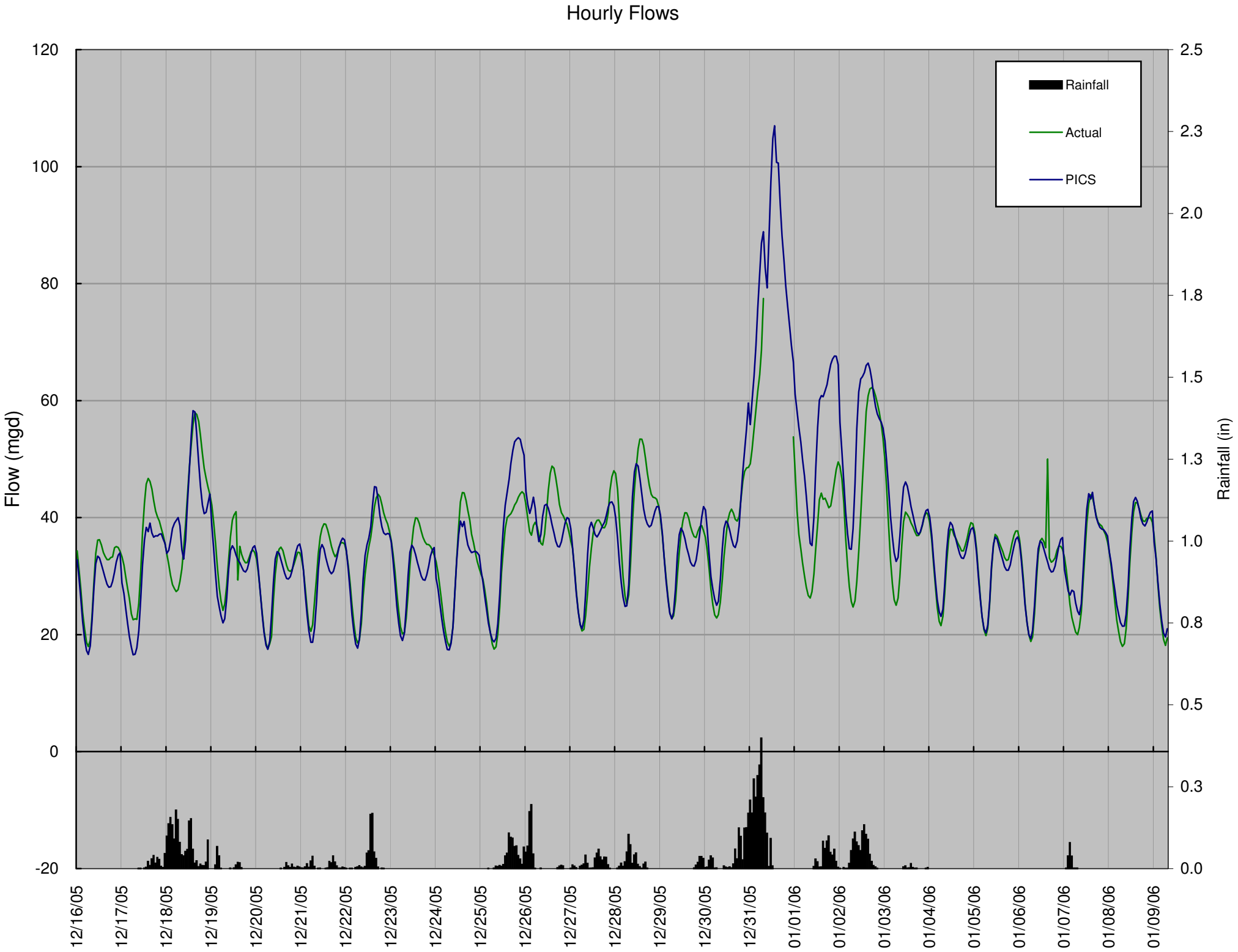
04/30/06


Hourly Flows
Rainfall
Actual
PICS
Flow (mgd)
Rainfall (in)
120
100
80
60
40
20
0
-20
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
12/16/05
12/17/05
12/18/05
12/19/05
12/20/05
12/21/05
12/22/05
12/23/05
12/24/05
12/25/05
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12/27/05
12/28/05
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12/31/05
01/01/06
01/02/06
01/03/06
01/04/06
01/05/06
01/06/06
01/07/06
01/08/06
01/09/06