RECLAMATION

Managing Water in the West

CHTR FISH RELEASE STUDY

FISH RELEASE PIPE MODEL STUDY

HYDRAULIC ANALYSIS

CHTR FISH RELEASE STUDY

FISH RELEASE PIPE MODEL STUDY

HYDRAULIC ANALYSIS

Brent Mefford, P.E.
Water Resources Research Laboratory
U.S. Bureau of Reclamation
Denver Technical Service Center
Denver, Colorado, 80225

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Acknowledgments

Jerry Fitzwater of the Water Resources Research Laboratory assisted in the installation of instrumentation and testing of the fish release model. Zaffar Eusuff, Javier Miranda and Roger Padilla, California Department of Water Resources, provided valuable assistance during the model testing and overall study guidance. Steve Hiebert, Fisheries Application Group (86-68290) provided program coordination.

This study was funded by the California Department of Water Resources.

Disclaimer

The information provided in this report is believed to be appropriate and accurate for the specific purposes described herein, but users bear all responsibility for exercising sound engineering judgment in its application, especially to situations different from those studied. References to commercial products do not imply endorsement by the Bureau of Reclamation and may not be used for advertising or promotional purposes.

Table of Contents

FISH RELEASE MODEL 6
Truck Tank - 6
Release Pipe and Downstream Pool – 7
Model Instrumentation - 7
FISH RELEASE PROCEDURE 8
Hydraulic Conditions During Fish Releases 8
Free surface Pipe Flow - 8
Pressurized Pipe Flow - 9
Hydraulic Jump Location – 9
Hydraulic Jump Length – 9
Tailwater – 9
Air Entrainment – 10
Shear – 10
MODEL TEST RESULTS 10
Air Venting - 10
Tailwater Suppression and Hydraulic Jump Length - 11
Auxiliary Flow – 11
Flushing of Debris – 11
PREDICTION OF HYDRAULIC CONDITIONS DURING A FISH RELEASE 12
3-DIMENSIONAL COMPUTATIONAL FLUID DYNAMICS (CFD) MODELING 12
CONCLUSIONS AND RECOMMENDATIONS 13
Recommendation No. 1 – 13
Recommendation No. 2 – 13
Recommendation No. 3 – 13
Recommendation No. 4 – 13
REFERENCES 14
APPENDIX - Model Test Hydraulic Data 33

List of Figures

Figure 1 – View of Horseshoe Bend release facility. 15
Figure 2 – View of Horseshoe Bend release site model facility. 15
Figure 4 – Haul tank water volume (gal.) with depth (inches). 17
Figure 5 – View of truck tank release gate. 17
Figure 6– Coefficient of discharge for a gate valve, Corps of Engineers Hydraulic Design Chart 330-1/1. 18
Figure 7 – Truck tank water depth (ft) versus flow (ft^3/s) as a function of percent gate opening. 18
Figure 8– View of release pipe passing through model tailwater tank. 19
Figure 9 – View of model release pipe inside tailwater tank. 19
Figure 10 – Pressure transducer (1psi) used to measure flow depth in pipe. 20
Figure 11 – View of data acquisition system. 20
Figure 12 – Normal depth in a 12 inch diameter smooth pipe. 21
Figure 13 – Flow velocity at contact with the tailwater as a function of pipe flow. 21

Figure 14 – Full pipe average flow velocity in 12 inch ID pipe. 22
Figure 15 – Vertical suppression of the hydraulic jump location in the fish release pipe as a function of pipe flow. 22
Figure 16– Froude number of free surface flow in fish release pipe. 23
Figure 18– Plots of selected model parameters measured during a fish release test conducted with no debris. 24
Figure 19 - Plots of selected model parameters measured during a fish release test conducted with normal (1x) debris load. 24
Figure 20 - Plots of selected model parameters measured during a fish release test conducted with four times (4x) normal debris load. 25
Figure 21– Simulation of flow conditions during a multiple-step gate opening. 25
Figure 22 – Simulation of flow conditions following a rapid gate opening. 26
Figure 23 – View showing the CFD model of the model fish release facility..... 26
Figure 24 – Numerical simulation of flow velocity (ft/s) in release pipe for stepped operation 5 sec after gate is opened. Gate 40 percent open. 27
Figure 25 – Numerical simulation of flow velocity (ft/s) in release pipe for stepped operation 20 sec after gate is opened. Gate 50 percent open. 27
Figure 26 - Numerical simulation of flow velocity (ft/s) in release pipe for stepped operation 60 sec after gate is opened. Gate 100 percent open. 28
Figure 27 - Numerical simulation of flow velocity (ft/s) in release pipe for stepped operation 90 sec after gate is opened. Gate 100 percent open. 28
Figure 28 - Numerical simulation of flow velocity (ft/s) in release pipe for stepped operation 110 sec after gate is opened. Gate 100 percent open. 29
Figure 29 - Comparison of hydraulic jump suppression determined by CFD model and specific force calculation. 29
Figure 30 - Numerical simulation of flow velocity (ft/s) in release pipe for full open gate operation 5 sec after gate is opened. Gate 100 percent open 30
Figure 31 - Numerical simulation of flow velocity (ft/s) in release pipe for full open gate operation 20 sec after gate is opened. Gate 100 percent open. 30
Figure 32 - Numerical simulation of flow velocity (ft/s) in release pipe for full open gate operation 40 sec after gate is opened. Gate 100 percent open. 31
Figure 33 - Numerical simulation of flow velocity (ft/s) in release pipe for full open gate operation 70 sec after gate is opened. Gate 100 percent open. 31
Figure 34 – CFD comparison of fish tank flow release for a typical stepped gate operation and a rapid fully opened gate operation. 32

FISH RELEASE PIPE MODEL STUDY

HYDRAULIC ANALYSIS

FISH RELEASE MODEL

The California Department of Water Resources (DWR) contracted with Reclamation to assist them with testing of a Fish Release Facility Model constructed by DWR at the Skinner Fish Facility near Tracy, California. The model was constructed to evaluate fish injury and survival during the restocking of fish salvaged at the Skinner Fish Facility. Photographs of the Horseshoe Bend release site and the CHTR model are shown in figures 1 and 2 and a profile view of the model is presented in figure 3.

Truck Tank - The fish haul truck is parked on a slope to facilitate total dewatering during a fish release (fig. 2). The truck tank used during the model tests held a maximum of 2500 gallons. For the tests, a maximum water level indicator was mounted on the downstream truck tank portal. Prior to each test the tank was filled to the indicator which corresponded to about 2250 gallons. The relationship of water volume in the tank set on the slope to water depth developed from field measurements conducted at the model are shown in figure 4 and represented by Equation 1.

$$Volume = -0.0125(D)^3 + 1.167(D)^2 + 29.103(D) \qquad \text{Eq. (1)}$$

where: D is depth in inches
Volume is in gallons

Flow from the tank is largely a function of the tank release gate discharge characteristics. The release gate is a 10” diameter knife gate, figure 5. The bottom of the gate leaf has a radius slightly larger than the pipe diameter. The relationship of flow to truck tank water depth is estimated by the coefficient of discharge for the knife gate. Hydraulic data on similar knife gates was not found. As a reasonable substitute, the coefficient of discharge for a gate valve was used. The coefficient of discharge relationship for free flow through gate valves developed by the Bureau of Reclamation is shown in figure 6. The relationship can be expressed by Equation 2.

$$Q = C_d A\sqrt{2gH} \qquad \text{Eq. (2)}$$

where: C_d = 0.0094*Percent Gate Opening

A = full open gate area, ft

g = acceleration of gravity, 32.2 ft/s^2

H =water depth upstream of gate referenced to the center line of the gate, ft

Figure 7 shows estimated flow from the gate based on equation 2 for four gate openings.

Release Pipe and Downstream Pool – Permanent release sites are used in the field to convey water, fish and debris from the fish haul truck to the river. The release pipes are permanently mounted on the river's bank at a 16% slope. Herein, release pipe distances along the pipe are referenced from the upstream end of the release pipe. A short section of 10 inch flexible pipe containing a 90 degree short radius elbow is used to connect the truck tank and release pipe. The upstream end of the flex-pipe is clamped onto the truck tank knife gate discharge pipe and the downstream end is slipped inside the larger radius release pipe. The outside diameter of the flex-pipe is approximately 0.5 inches less than the inside diameter of the release pipe. The model release pipe is 12 inch I.D. acrylic pipe 97.25 ft long mounted on a 9 degree slope (16 percent). Pumped auxiliary flow can also be injected to the release pipe through a four path manifold located approximately 8 ft from the upstream end of the release pipe.

Above the tailwater, the model was a full scale representation of DWR's release facilities. In the model, the river was simulated by a 16 ft wide by 30 ft long by 8 ft deep fiberglass pool. The release pipe passes through the tank wall (figure 8) and extends into the pool about 18 ft, figure 9. The length of submerged release pipe was shortened compared to the prototype pipe to fit within the model tailwater tank. The model release pipe extends about 4.2 ft below the tailwater, a slope length of about 23.5 ft. The Horseshoe Bend release pipes extend approximately 10 ft below the mean water surface, a slope length of 62.5 ft.

Model Instrumentation - Pressure transducers were installed on the haul truck fish tank, at 10 ft intervals along the release pipe invert and on the tailwater tank to measure water depth during the release process, figure 10. The opening of the truck tank release gate was measured using a linear position string transducer mounted on the top of the gate leaf. An attempt was made to continuously measure release flow by mounting a strap-on acoustic flow meter on the release pipe below the tailwater at the junction of the release pipe and the tailwater tank. This proved unsuccessful due to excessive air entrainment in the flow. An alternative method based on measuring the change in truck tank volume during each time step was used to determine flow. The instrumentation was recorded at 1.6 second intervals during a fish release using a 24 bit precision analog to digital multiplexer. The data for each test was downloaded directly to a laptop computer, figure 11.

FISH RELEASE PROCEDURE

Water, fish and debris were injected to the model release pipe following typical procedures used for prototype releases. Prior to each test, the fish haul truck was filled with about 2,250 gallons of water. Test fish were added to the truck tank along with selected quantities of debris. For all tests, approximately 0.18 ft^3/s auxiliary flow was pumped into the release pipe. The auxiliary flow was started prior to fish release and continued for several minutes after the truck tank was empty. Auxiliary flow and the injection manifold were similar to the prototype.

Release of flow and fish from the truck tank is initiated by opening the truck tank knife gate. The gate is operated by an air cylinder using the truck's compressed air system. The compressed air gate actuator made opening the gate to set positions difficult. The gate frequently moved in jerky movements. Operators from the Skinner Fish Facility provided guidance on how the knife gate is typically opened during releases at the prototype release sites. The gate is initially opened a few inches to limit flow. This is necessary to prevent water from blowing back out pipe as air displaced by water escapes. The only exit path for air to escape through is a narrow crescent shaped area lying between the outside of the flexible pipe and the inside of the release pipe. Typically the operators wait about 30 seconds for the water level in the tank to drop and the initial air surge to bleed off before opening the gate to about 50 percent open where they again pause for about 20 seconds before fully opening the gate. There is not a standard for opening the track gate. Each operator has their preferred method of opening the gate.

Hydraulic Conditions During Fish Releases

The hydraulics of the fish release process is, by its nature, unsteady flow. As the tank drains the driving head on the system and therefore flow continuously decrease for a fixed gate opening. Predictable relationships between gate opening, tank water depth and release flow were affected by pressure surges in the pipe caused by poor air venting and to a lesser degree, debris movement through the system. Additional variability of operation was introduced by the poor control of truck tank release gate positioning.

Free surface Pipe Flow - Flow from the truck tank passes down the pipe as free surface flow until intercepting the tailwater. The smooth acrylic pipe is sufficiently long to allow the flow to reach normal depth upstream of the tailwater. Flow depth and velocity at the tailwater for a known discharge can be determined by iteration from the well known Manning's equation. The Manning's Formula for uniform flow in an open channel expressed in English units is,

$$Q = A\frac{1.49}{n}R^{2/3}S^{1/2} \qquad \text{Eq. (3)}$$

where: Q = discharge, ft^3/s
A = flow area
n = Manning's coefficient of roughness
R = channel hydraulic radius, ft (ratio of water area to wetted perimeter)
S = slope of the energy grade line

Model flow versus normal depth in the release pipe for a Manning's *n* value of 0.01 is given in figure 12 and average flow velocity at contact with the tailwater is given in figure 13. The prototype steel release pipes would be rougher than the acrylic pipe used in the model. Depending on pipe condition, Manning's n values for the prototype pipe would likely be in the range of 0.012 to 0.014.

Pressurized Pipe Flow - Free surface pipe flow jumps to pressurized full-pipe-flow upon intercepting the tailwater within the pipe. The velocity of pressure flow downstream of the hydraulic jump is inversely related to pipe area. Average flow velocity (ft/s) is approximately 1.27 times flow expressed in cubic feet per second, figure 14.

Hydraulic Jump Location – The momentum of the free surface pipe flow upon contacting the tailwater suppresses the tailwater within the pipe below the surrounding tailwater level, moving the hydraulic jump downstream. The suppression of the jump can be estimated by determining where the specific force of the pipe flow is equal to the specific force exerted by the tailwater. The specific force of the flow at a section is defined as the force due to the momentum of the flow plus the force due to hydrostatic pressure and the weight of water in the jump acting in the direction of flow as given in equation 4.

$$Specific\ Force / w = Q^2 / (gA_1) + (z_c A_1) + (A_2 + A_1)/2 * L_j \sin(\vartheta) \qquad \text{Eq. (4)}$$

where: Q = discharge, ft^3/s
A_1 = cross sectional flow area upstream of jump, ft^2
A_2 = cross sectional flow area downstream of jump, ft^2
g = acceleration of gravity, ft/s^2
Z_c = distance from the flow surface to the flow centroid, ft
L_j = length of hydraulic jump, ft
w = weight of water, lbs/ft^3
ϑ = angle of pipe with horizontal

Vertical suppression of the jump in the release pipe based on equation 4 is given in figure 15. A 3rd degree polynomial regression equation was fit to the data to develop algorithms for estimating jump suppression for fish releases.

Hydraulic Jump Length – No studies of hydraulic jump lengths in shallow sloping pipes were found during the literature search. However, a reasonable approximation of jump length can be determined from physical model studies of jumps in horizontal pipes conducted by Stahl and Hager (1999). They defined jump length in terms of a recirculation zone and air entrainment zone. The recirculation zone (L_r) extends from the upstream jump toe downstream to the surface stagnation point. The air entrainment zone (L_a) extends from the upstream toe downstream to the point where most of the entrained air has reached the pipe crown. The study results suggest $L_r = 2h_2F_1^{1/2}$, where h_2 is the jump downstream sequent depth and F_1 is the approach flow Froude number. The length of the air entrainment zone was found equal to $2L_r$. The relationship between F_1 and release pipe flow is shown in figure 16.

Tailwater – Tailwater was measured using a pressure transducer mounted near the floor of the tailwater tank. All flow released from the fish haul truck was retained in the

tailwater tank during a test. Prior to each test the initial tailwater elevation was set to achieve ~ 4.2 ft of submergence on the downstream end of the release pipe. During the tests the tailwater elevation increased ~12.5 inches.

Air Entrainment – At the interface of free flow and pressure flow, the hydraulic jump transfers free air from upstream of the jump into the pressure flow downstream. In a sloping pipe the entrained air may be carried down the pipe by flow or travel up the pipe against the flow due to buoyancy. The movement of air bubbles in flow in a sloping pipe is shown in figure 17, Falvey (1980). The range of hydraulic conditions and air pocket movement that could occur during a fish release are indicated on the plot by a heavy line. The data indicates air bubbles will travel upstream when release pipe flow is less than about 2.8 ft^3/s and downstream when flows are higher. Because flow decreases as the truck tank empties, a transition will occur where air bubbles that were moving down the pipe fail to escape prior to the discharge falling below 2.8 ft^3/s. Free air remaining in the pipe will then run up the pipe consolidating into larger slugs as downstream bubbles overtake upstream bubbles. When air pockets reach the free surface the pockets contain compressed air that rapidly expands at the water surface. This action is referred to as blowback. The action of air pockets blowing back was evident in the model. Visual observation of flow in the model revealed rapid swings in the location of the hydraulic jump as the truck tank approached empty. The pressure swings observed were likely a combination of blowback and restricted air venting of the free flow zone.

Shear – Exposing fish to excessively strong shear flows has been shown to result in scale loss, bruising or mortality, (DOE, 2000)**.** The maximum rate of fluid strain in a hydraulic jump can be approximated by high velocity flow entering a pool. Rate of fluid strain is defined as the change in velocity magnitude divided by distance normal to the flow direction (Δy). In the DOE study, shear effects on multiple salmonid fingerlength and juvenile age classes and yearling American shad were tested. All strain rates were based on a Δy of 0.7 inches, the approximate width of a juvenile salmonid fish. The study found no significant injuries to fish occurred at strain rates < 517 in/s/inch. Limited predation tests were also conducted on rainbow trout. These tests indicated that increased susceptibility to predation occurred at lower strain rates than the onset of injuries. A rate of strain of 517 in/s/in at 0.7 inches would require a flow velocity of about 30 ft/s entering a still pool. Maximum velocity in the model reached about 25 ft/s (figure 13) or a maximum rate of strain of 428 in/s/in.

MODEL TEST RESULTS

In the study, 106 tests were conducted to investigate the influence of operation and debris load on fish survival during the release process. Figures 18, 19 and 20 present selected data measured during typical tests conducted with no debris, normal debris and four times normal debris loads. The data plots illustrate how flow conditions change with time during the fish release process. Similar graphs for each test run are given in the hydraulic testing appendix.

Air Venting - Of particular note are the test data for pipe station 12 presented in figure 18 which shows a sharp rise in pipe pressure immediately following gate opening. The pressure rise is due to compression of air in the pipe caused by a rapid release of water

into the pipe with restricted air venting. The pressures shown resulted from an initial gate opening of 60 percent. Figures 19 and 20 show a much reduced pressure rise due to air compression following initial gate stroke openings of 40 to 45 percent. As discussed previously, a rapid pressurization of the pipe results in air and water blowing back through the annulus between the fixed pipe and flex pipe used during a release and is typically avoided by operators by opening the gate less than about 40 percent for a period of 20 to 30 seconds while air bleeds out of the pipe.

Tailwater Suppression and Hydraulic Jump Length - Also of note in figures 18-20, are pressures measured at pipe stations 82 and 97. These locations are located below normal tailwater. In all three tests, the tailwater is suppressed for a period of time below pipe sta. 82 as indicated by a sharp drop in pressure during the release process. In figure 18, pressures measured at sta. 97 indicate an initial gate opening 60 percent resulted in the hydraulic jump (free flow-tailwater interface) moving to nearly the pipe terminus for about 15 seconds before retreating. Test data shown in figures 19 and 20 with smaller initial gate openings indicate the hydraulic jump remains upstream of sta. 97 throughout the release. However, large pressure fluctuations at sta. 97 indicate the hydraulic jump length extends to the end of the pipe during much of the release.

Auxiliary Flow – A constant auxiliary flow of 0.18 ft^3/s was supplied to the release pipe starting prior to each test and continued several minutes after the truck tank was emptied. The small auxiliary flow had little effect on release pipe hydraulics. The auxiliary flow adds 0.14 ft/s to the full pipe flow velocity.

Flushing of Debris – Flushing of debris through the release system requires material be carried by flow from the truck tank, passed through the control gate and a 90-degree-mitered elbow before entering the release pipe. Material must then be carried by free surface flow down the pipe to the hydraulic jump, pass through the jump and be carried in full pipe flow to the pipe exit. The addition of four times the normal debris load was found to have little effect on release flow conveyance. Drawing direct comparisons of flow conditions with different debris loads was not possible due our inability to closely control the truck release gate opening and differences in debris characteristics (buoyancy and consistency) between tests. To evaluate debris effects on flow conveyance, coefficient of discharge (C_d) values were calculated for a full and partial gate opening conditions under similar hydraulic heads. Ten values for tests conducted with no debris were compared to 10 tests conducted with 4X debris. The C_d values were not statistically different at a 95 percent confidence level. This indicates no significant reduction in flow conveyance typically occurs due to debris at the concentrations tested. However, significant clogging was observed following many 4x debris tests at both the gate and elbow. We could not determine from the tests when clogging occurred during the release process. Clogging most likely occurred near the end of the release process when flow is rapidly declining and large quantities of floating debris are being pulled into the release pipe.

Following all debris tests, significant debris also remained in the release pipe within the tailwater. The retention of debris in the pipe following a release is affected by a combination of factors including debris characteristics and flow conditions. Highly buoyant debris is likely expelled from the haul tank during the final stages of the release process when release flow is significantly reduced. Debris that is positively buoyant may

either pass through the jump or become entrained in the recirculation flow that occurs on the face of the hydraulic jump. Entrapment of highly buoyant debris in the recirculation zone of a hydraulic jump is nearly independent of flow. Entrapment may persist during large and small flows. Highly buoyant debris passed through the jump can be assumed to move similar to an air pocket as discussed in the air entrainment section. Therefore, to transport highly buoyant material downstream requires a sustained flow rate greater than about 2.8 ft^3/s for sufficient time for material to travel the length of submerged pipe. Considering buoyant debris is most likely to be flushed from the truck tank during the final stages of a release, sufficient auxiliary flow was not provided during the model tests to move buoyant material out of the release pipe.

PREDICTION OF HYDRAULIC CONDITIONS DURING A FISH RELEASE

The hydraulic relationships presented describe the general behavior of the flow during a fish release. The relationships can be used to estimate average hydraulic conditions for different release gate operations. Figures 21 and 22 show flow conditions for a fish release using a typical stepped gate operation and a quick open gate release, respectively.

3-DIMENSIONAL COMPUTATIONAL FLUID DYNAMICS (CFD) MODELING

A three dimensional CFD model of the model release facility was developed to further investigate the hydraulics of the release process. The CFD model included the truck tank, 10 inch release gate and insertion pipe, fixed 12 inch diameter release pipe, auxiliary flow and tailwater tank, (figure 23). The numerical model was used to simulate the unsteady flow conditions of a release, validate the analytical prediction of tailwater suppression presented and extend the study results to include hydraulic conditions for a full gate opening release. The compression of air in the release pipe was not included in the model. Two simulations of fish releases in the physical model were conducted. The first simulation modeled a release using a stepped gate opening similar to that used in the physical model. The truck gate was initially opened to 40 percent (4 inches) of the full gate stroke for 20 seconds and then increased to 50 percent gate stroke for ten seconds followed by opening the gate 100 percent. For each simulation 0.18 ft^3/s was added as auxiliary flow. Flow velocity plots of the fish haul tank and downstream release pipe at different times during a release are presented in figures 24 to 28. The simulations show flow velocity throughout the release facility and the suppression of the hydraulic jump with flow. Hydraulic jump suppression predicted from the CFD modeling compared well with calculations using the specific force method, figure 29. Flow simulations of opening the release gate to 100 percent initially are shown in figures 30 to 33. Figure 34 shows a comparison of the volume of flow released with time. The stepped opening requires about 125 seconds for the tank to drain compared with about 75 seconds when the release gate is fully opened initially. Computer generated animations of flow conditions during the entire fish release process for both gate sequences modeled are provided separate from this report.

CONCLUSIONS AND RECOMMENDATIONS

The tests provided significant insight into the hydraulics of the fish release process used by the State of California at the Skinner Fish Salvage Facility. The testing identified several issues that hinder the performance of the release process and identified several areas that require additional investigation to fully understand the complex relationships between release operation, fish and debris. All model results presented should not be assumed to fully represent prototype conditions. Non-similarity of submerged pipe length between model and prototype will affect some results related to flushing of debris and fish from the release pipe. Prototype flushing efficiency (significantly longer length of submerged pipe) would likely be less than observed in the model. The length of the hydraulic jump in the model generally extended to the end of the model pipe. In the prototype release facilities, the jump would always reside fully within the pipe. This non-similarity of the model does not affect the general findings of the study.

Recommendation No. 1 – An air relief valve or gooseneck vent pipe should be installed on the crown of the release pipe downstream of the auxiliary flow manifold. Installing air venting would allow the truck tank gate to be rapidly opened to 100 percent. Rapid opening of the gate would reduce the chance of fish injury resulting from fish and debris passing through small gate openings and improve debris flushing. Flow conditions during a rapidly opened gate release were estimated by relating the previously described flow and facility relationships derived from the model tests in a time step simulation. A spreadsheet was setup to simulate a stepped gate opening release similar to existing practice and a rapid gate opening release (figures 23 and 24). Benefits to pipe flushing will result from rapidly opening the release gate which provides the maximum peak flow, maximum tailwater suppression and maximum full pipe flow velocity that can be achieved independent of auxiliary flow.

Recommendation No. 2 – The tests demonstrated current practice does not effectively flush the submerged length of release pipe. Auxiliary flow should be increased following a release to about 3.5 ft^3/s and sustained for a minimum of five minutes to flush the system.

Recommendation No. 3 – The 90 degree mitered elbow should be eliminated or replaced with a longer radius bend that is permanently attached to the fixed release pipe. This would reduce or eliminate clogging of the elbow that was observed during model testing.

Recommendation No. 4 – Gate actuators on the fish haul trucks should provide consistent gate control. During the model testing, the gate frequently stopped as much as 10 percent short of full open. The variability in perceived 100 percent gate opening was only recognized by measurements of gate stroke recorded during the model testing.

REFERENCES

Department of Energy (DOE), 2000. Laboratory Studies on the Effects of Shear on Fish: Final Report, Idaho Operations Office, DOE ID-10822.

Falvey, H., 1980. Air-Water Flow in Hydraulic Structures, Engineering Monograph 41, U.S. Bureau of Reclamation, Water and Power Resource Services, Engineering and Research Center, Denver, Co., p.51.

Stahl, H. and Hager, W., 1999. Hydraulic Jump in Circular Pipes, Canadian Journal of Civil Engineering No. 26, pp. 368-373.

Figure 1 – View of Horseshoe Bend release facility.

Figure 2 – View of Horseshoe Bend release site model facility.

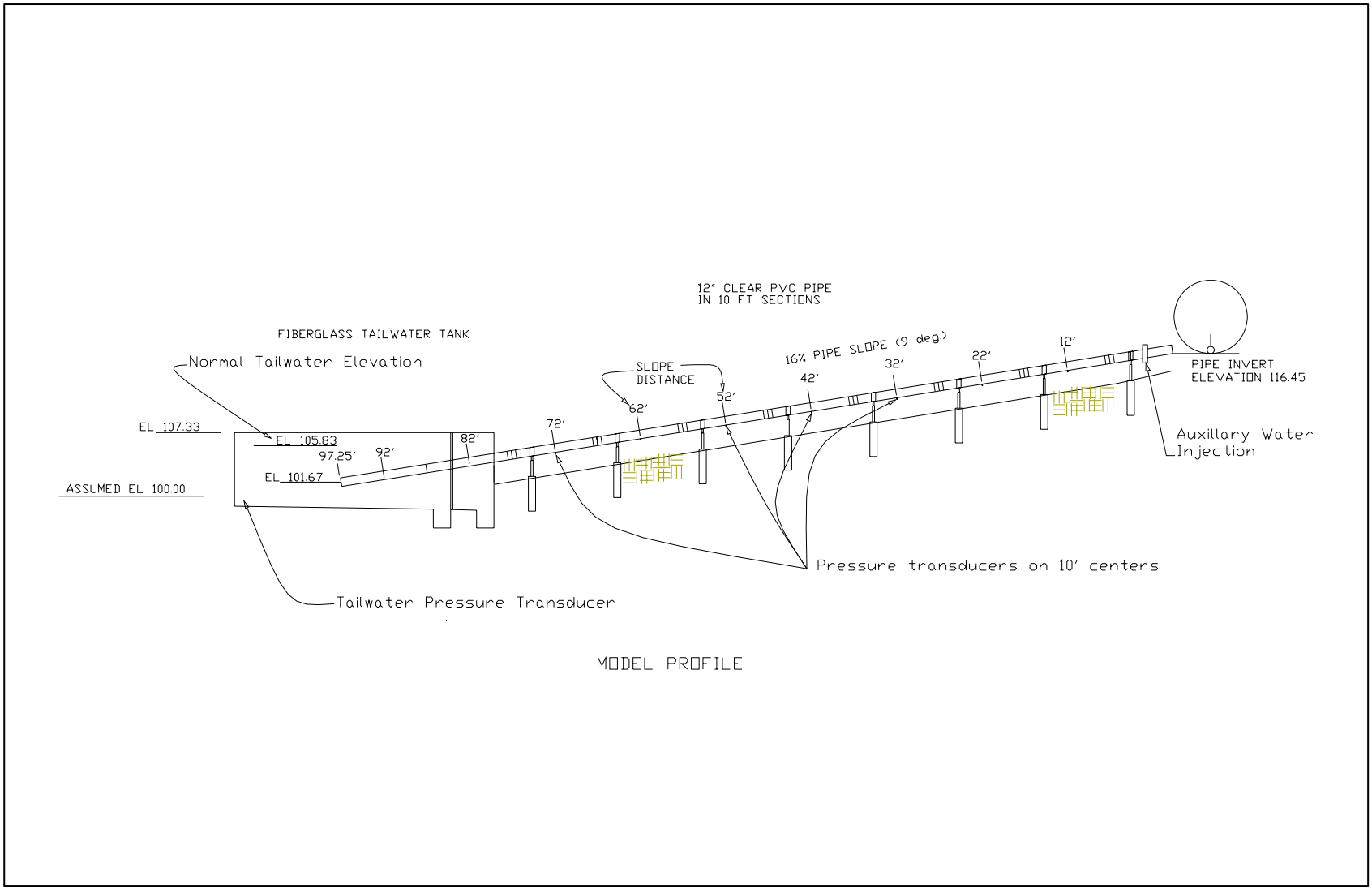


Figure 3 - Profile view of fish release model..

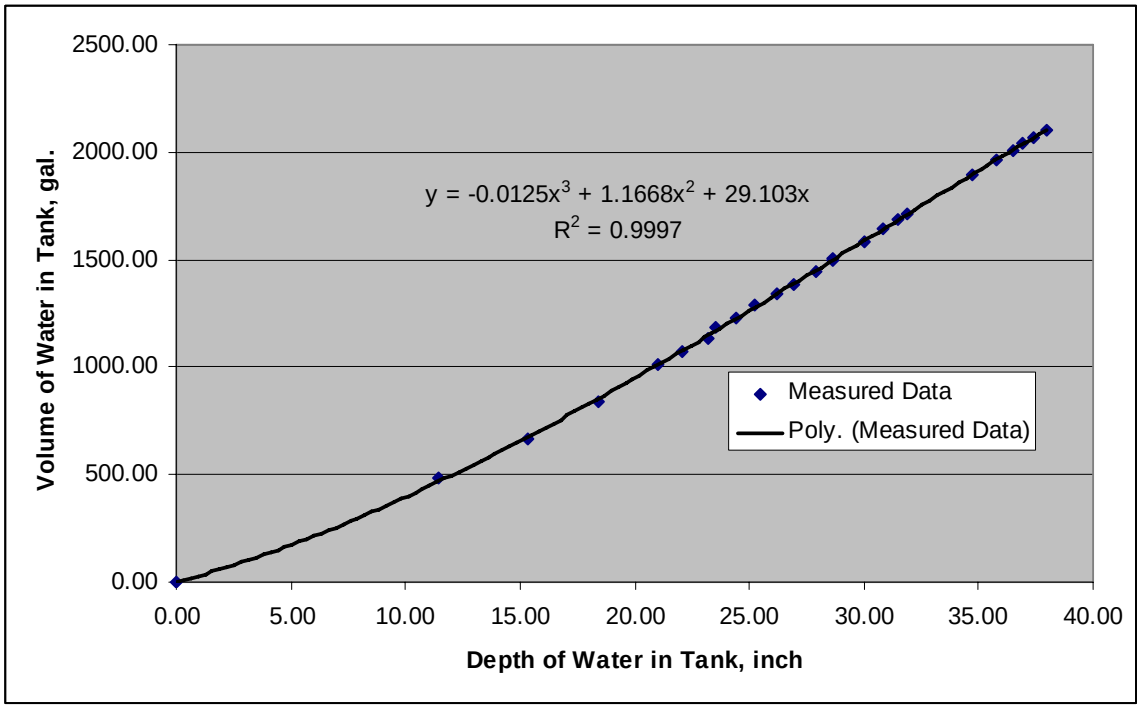


Figure 4 – Haul tank water volume (gal.) with depth (inches).

Figure 5 – View of truck tank release gate.

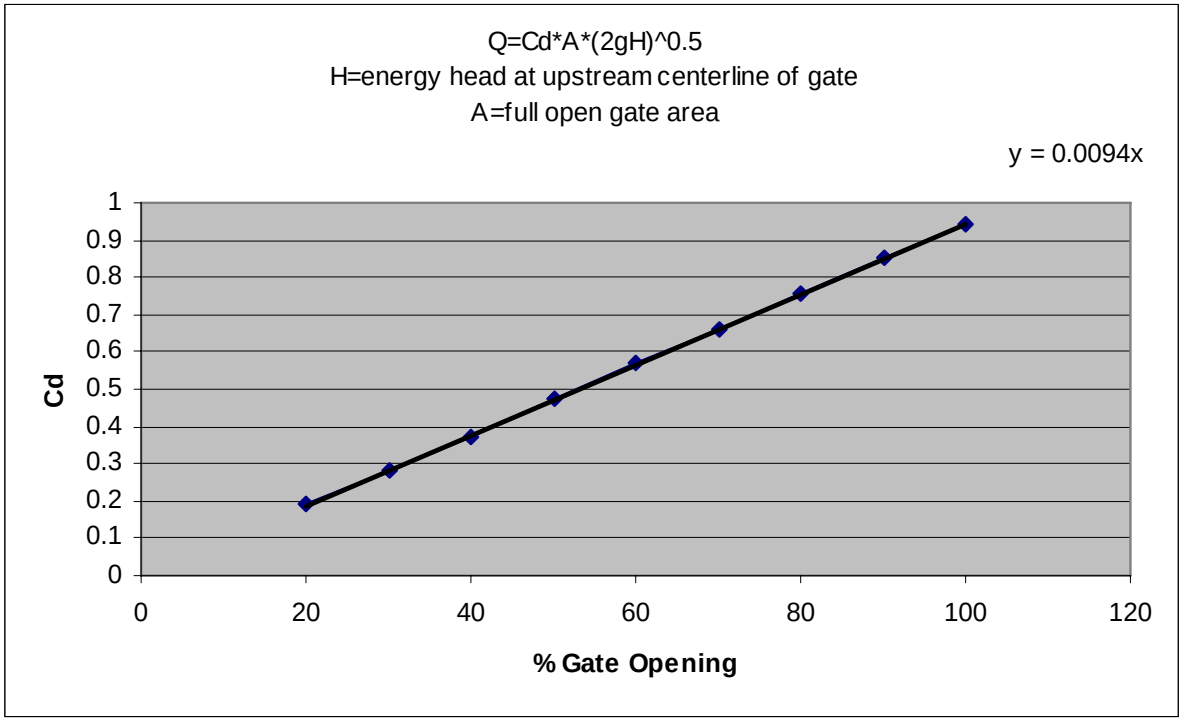


Figure 6– Coefficient of discharge for a gate valve, Corps of Engineers Hydraulic Design Chart 330-1/1.

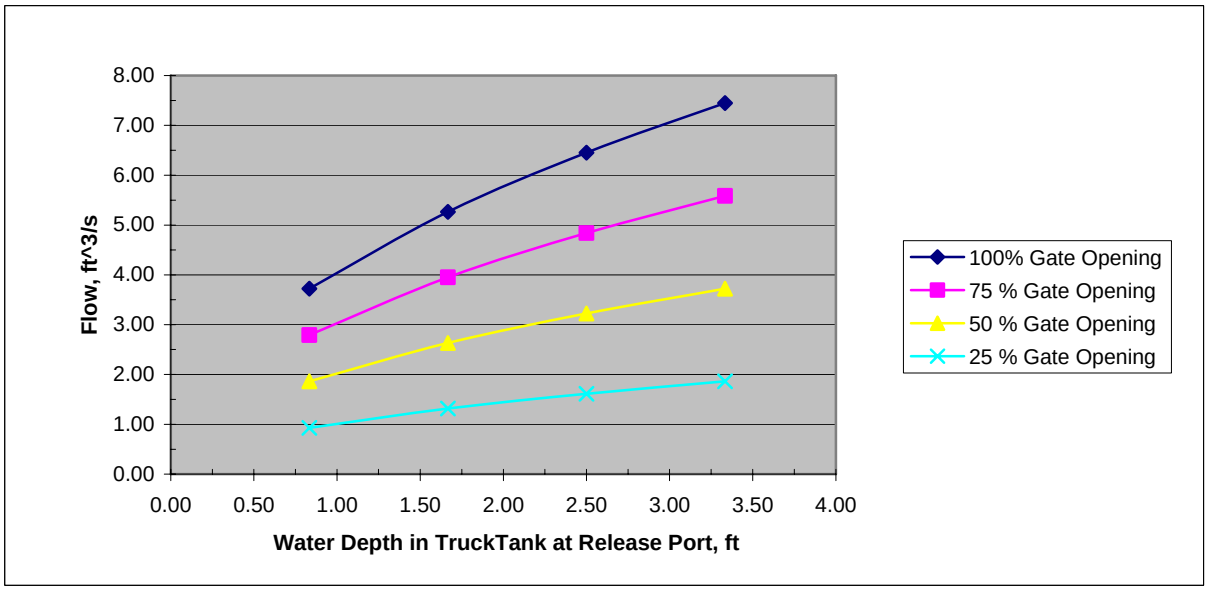


Figure 7 – Truck tank water depth (ft) versus flow (ft^3/s) as a function of percent gate opening.

Figure 8– View of release pipe passing through model tailwater tank.

Figure 9 – View of model release pipe inside tailwater tank.

Figure 10 – Pressure transducer (1psi) used to measure flow depth in pipe.

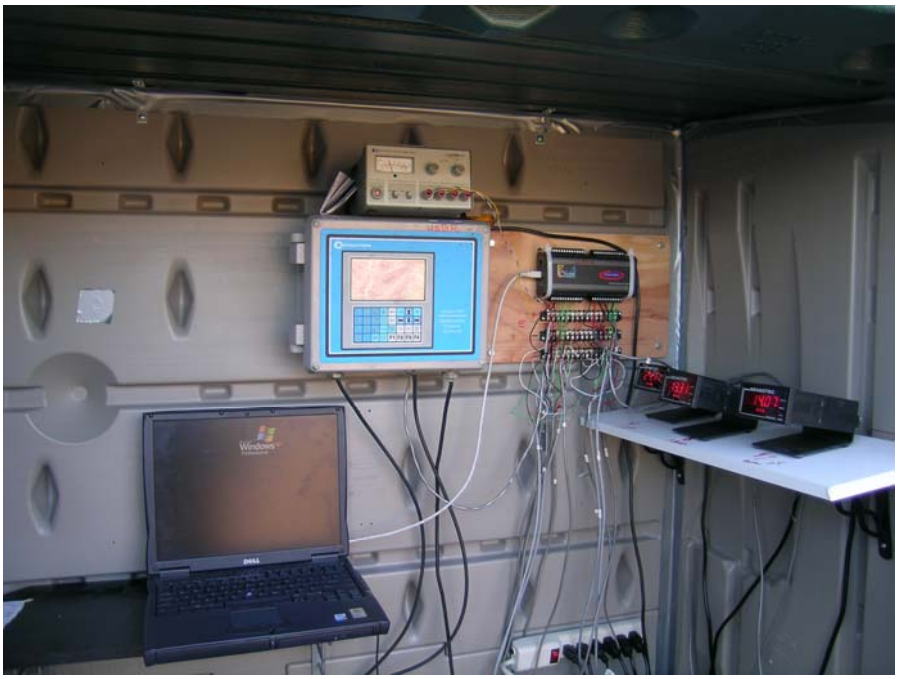


Figure 11 – View of data acquisition system.

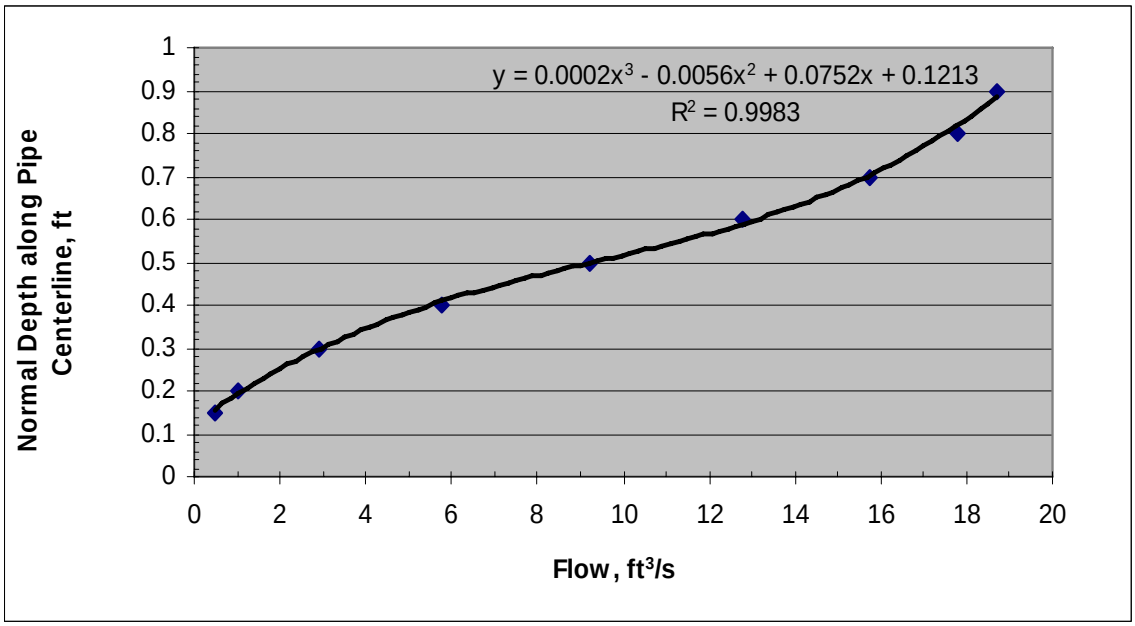


Figure 12 – Normal depth in a 12 inch diameter smooth pipe.

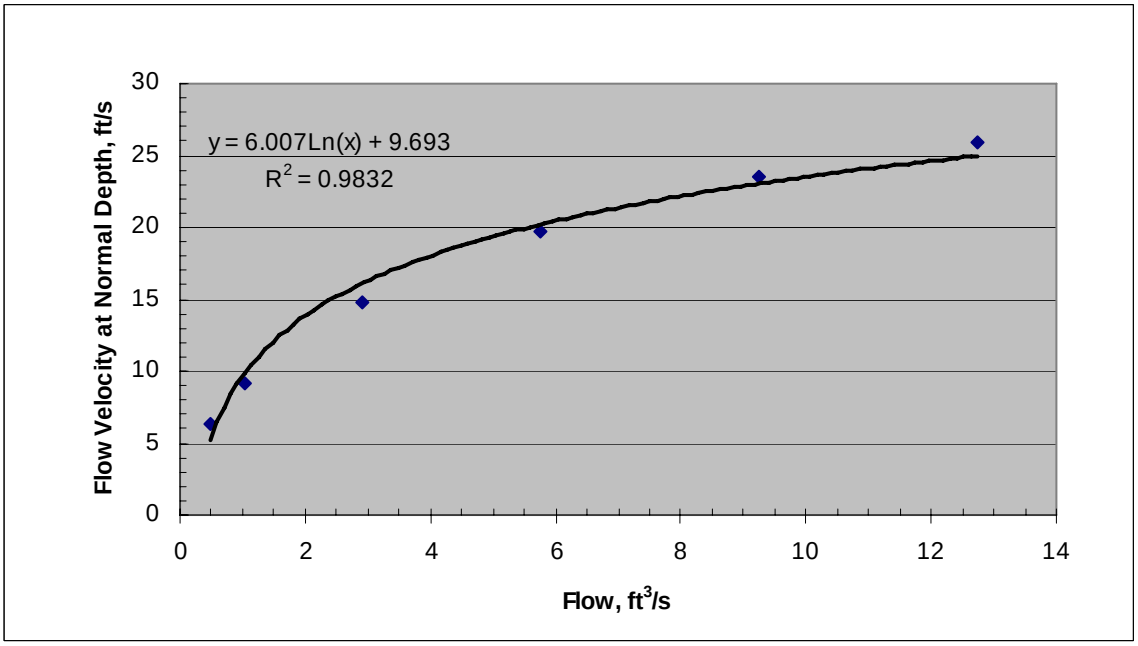


Figure 13 – Flow velocity at contact with the tailwater as a function of pipe flow.

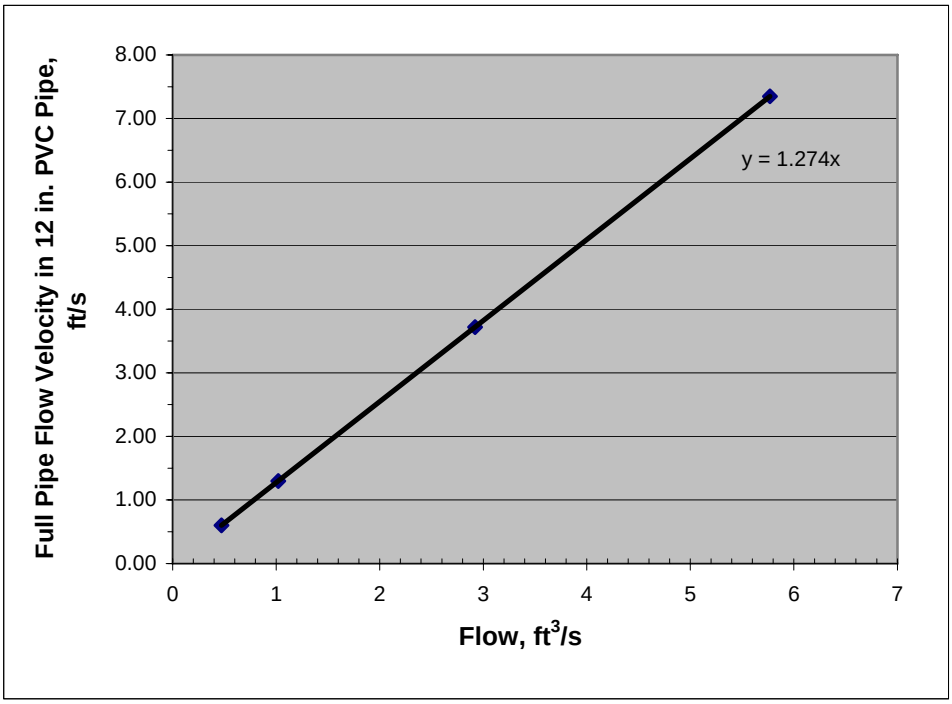


Figure 14 – Full pipe average flow velocity in 12 inch ID pipe.

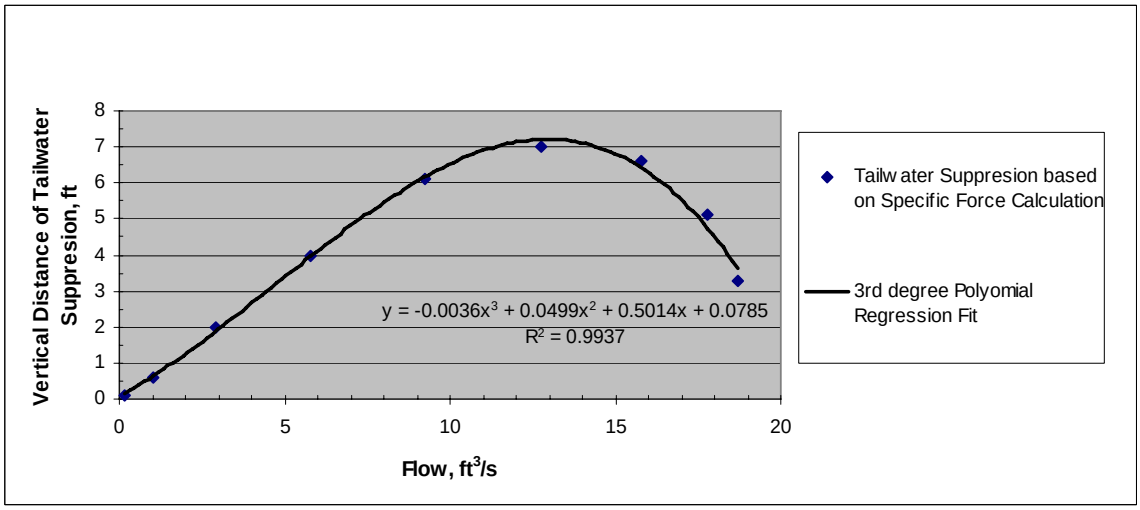


Figure 15 – Vertical suppression of the hydraulic jump location in the fish release pipe as a function of pipe flow.

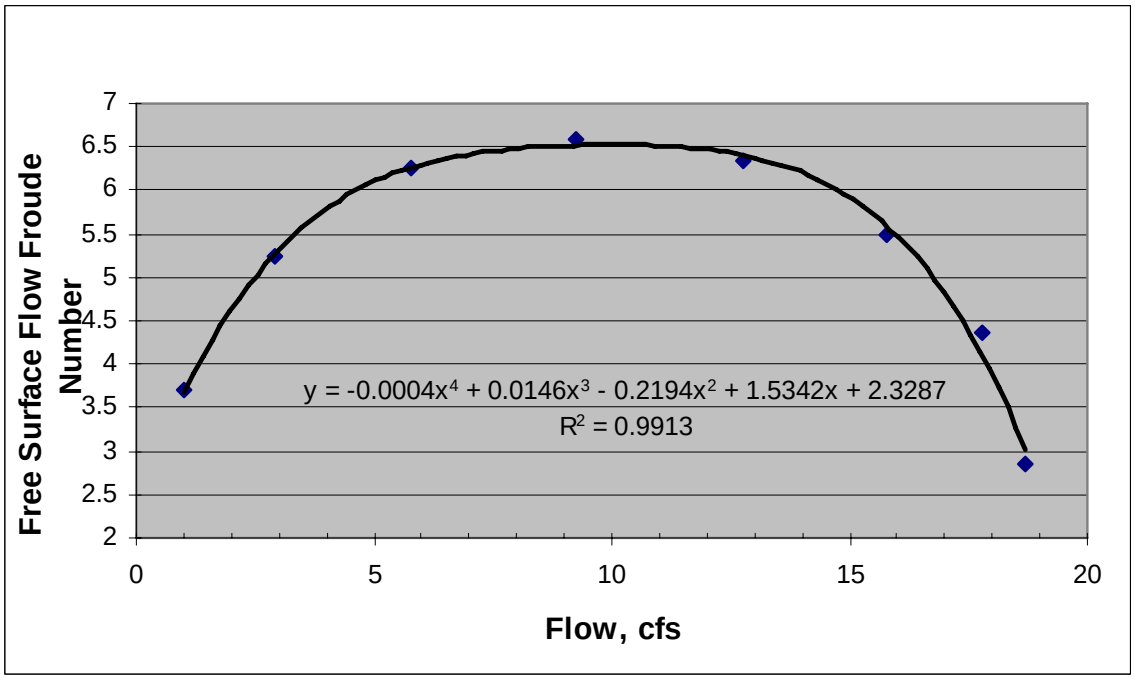


Figure 16– Froude number of free surface flow in fish release pipe.

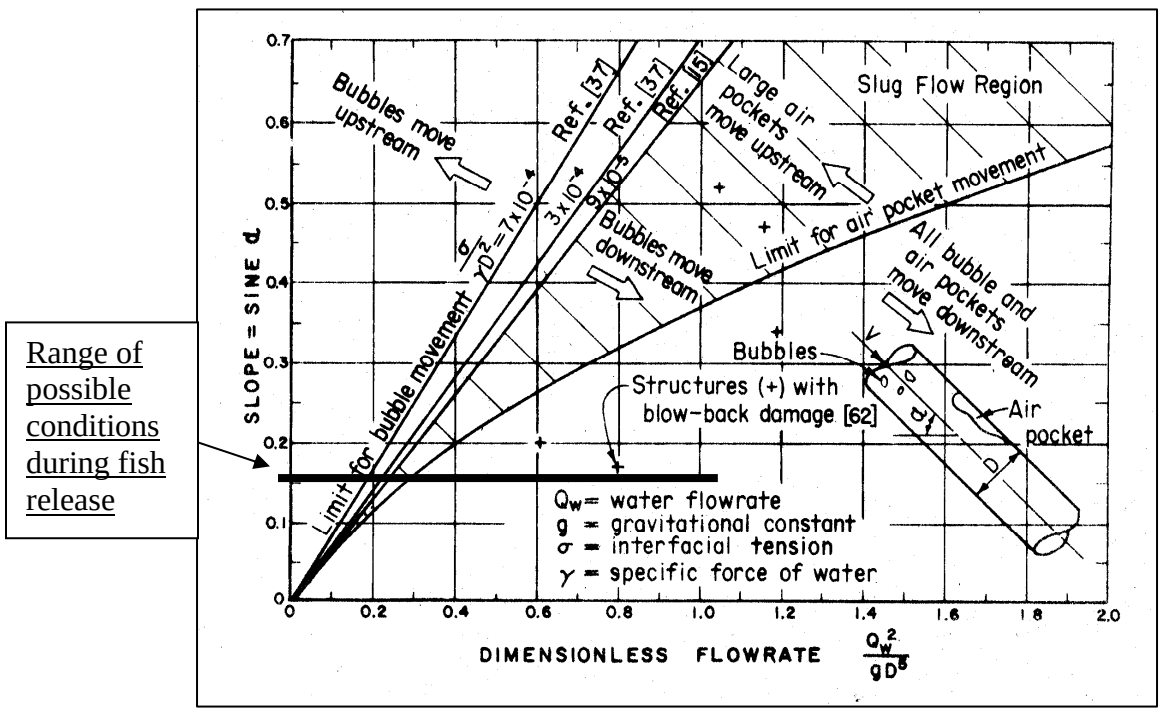


Figure 17– Air bubble movement in a sloping pipe, Falvey 1980.

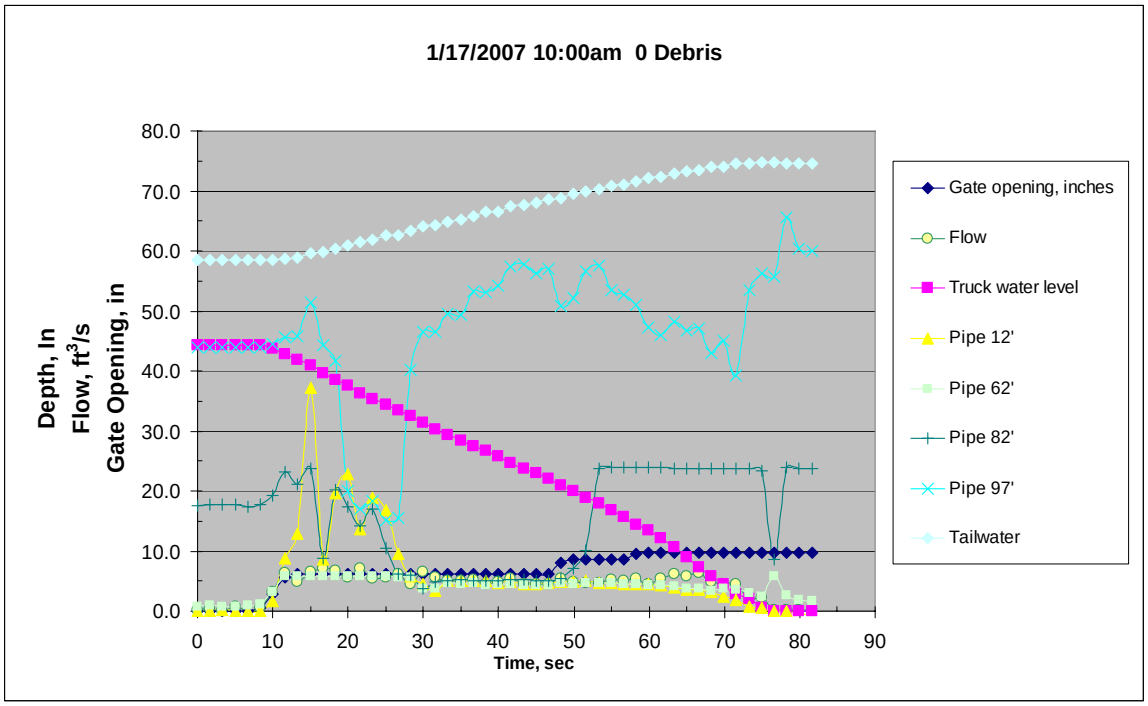


Figure 18– Plots of selected model parameters measured during a fish release test conducted with no debris.

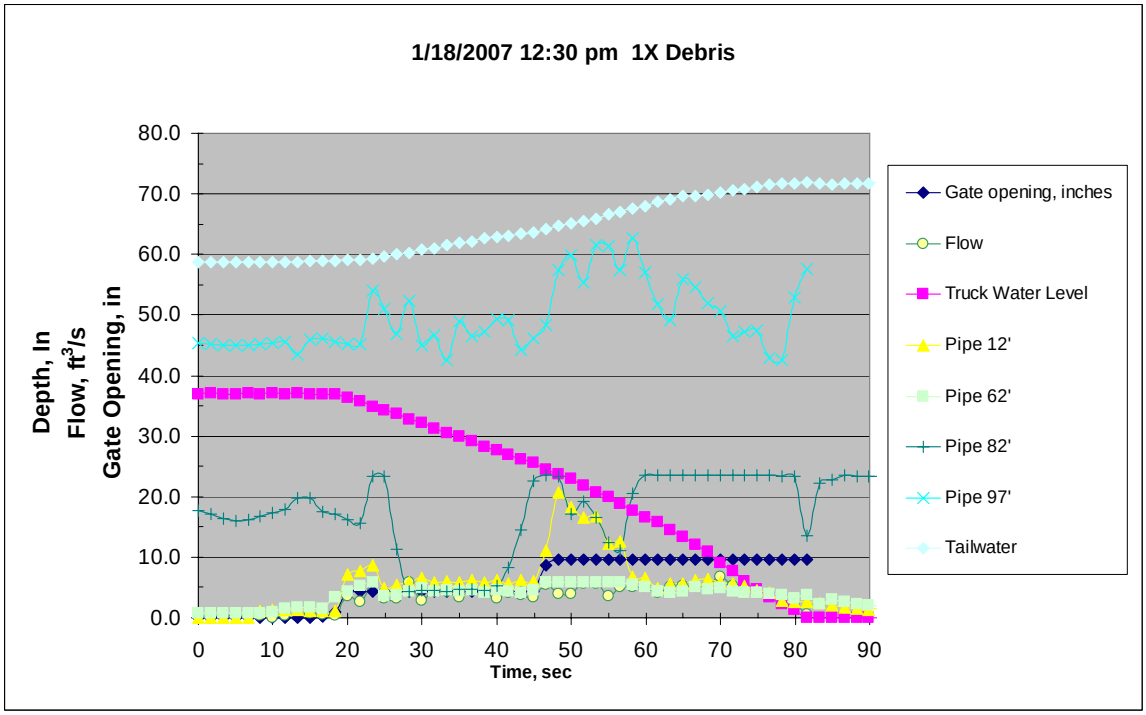


Figure 19 - Plots of selected model parameters measured during a fish release test conducted with normal (1x) debris load.

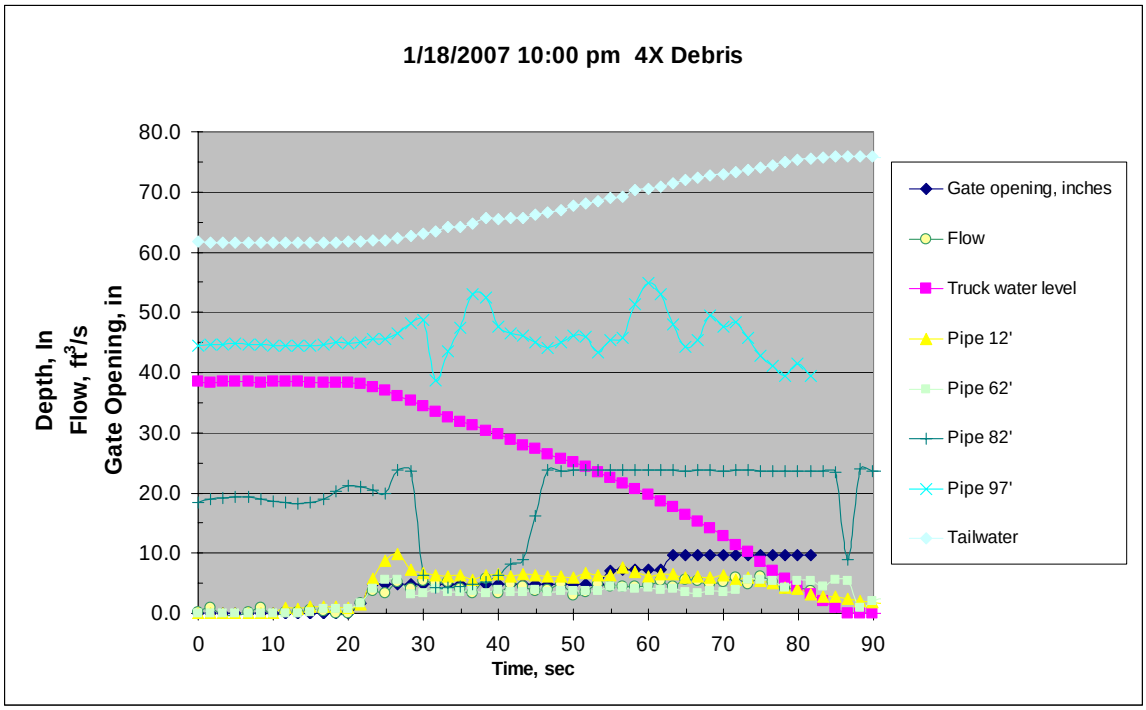


Figure 20 - Plots of selected model parameters measured during a fish release test conducted with four times (4x) normal debris load.

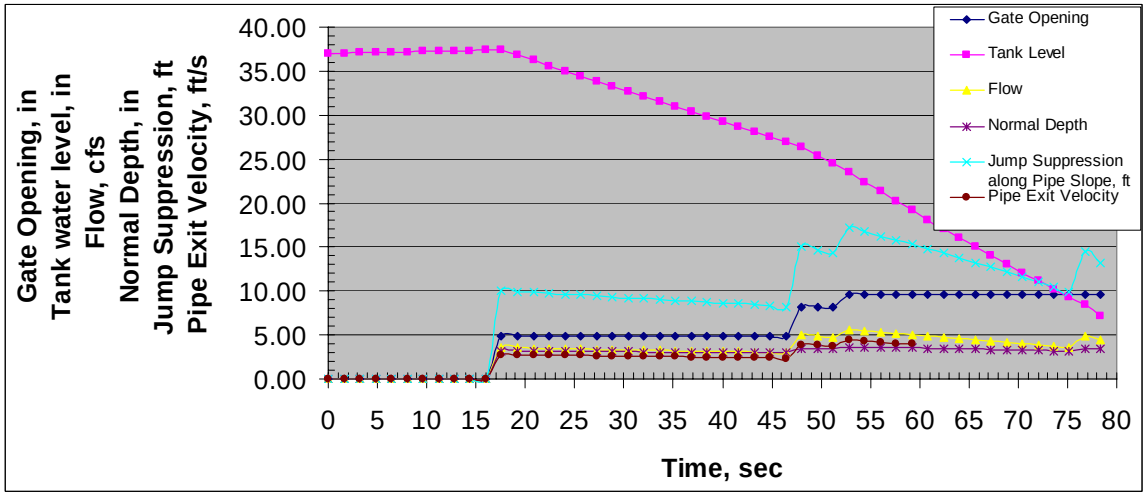


Figure 21– Simulation of flow conditions during a multiple-step gate opening.

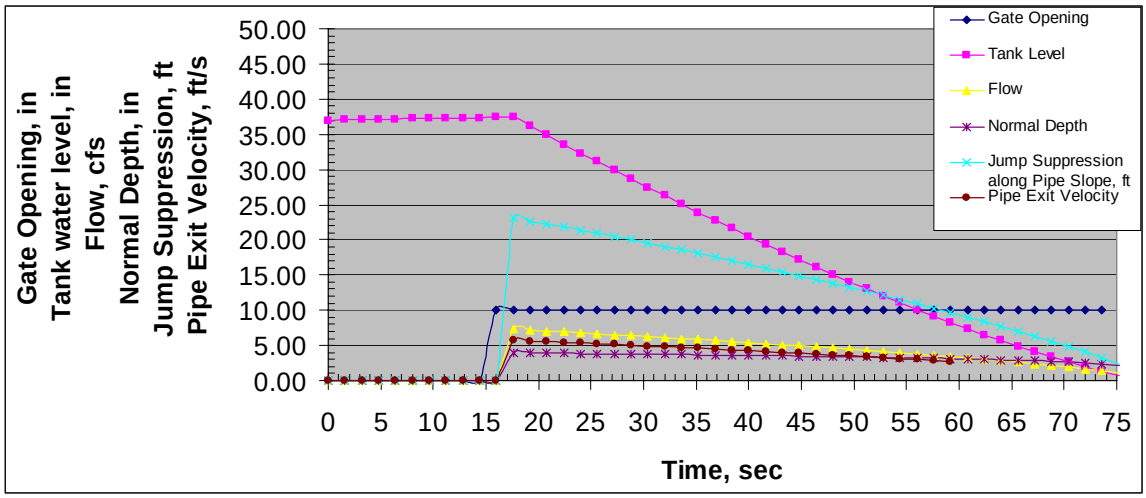


Figure 22 – Simulation of flow conditions following a rapid gate opening.

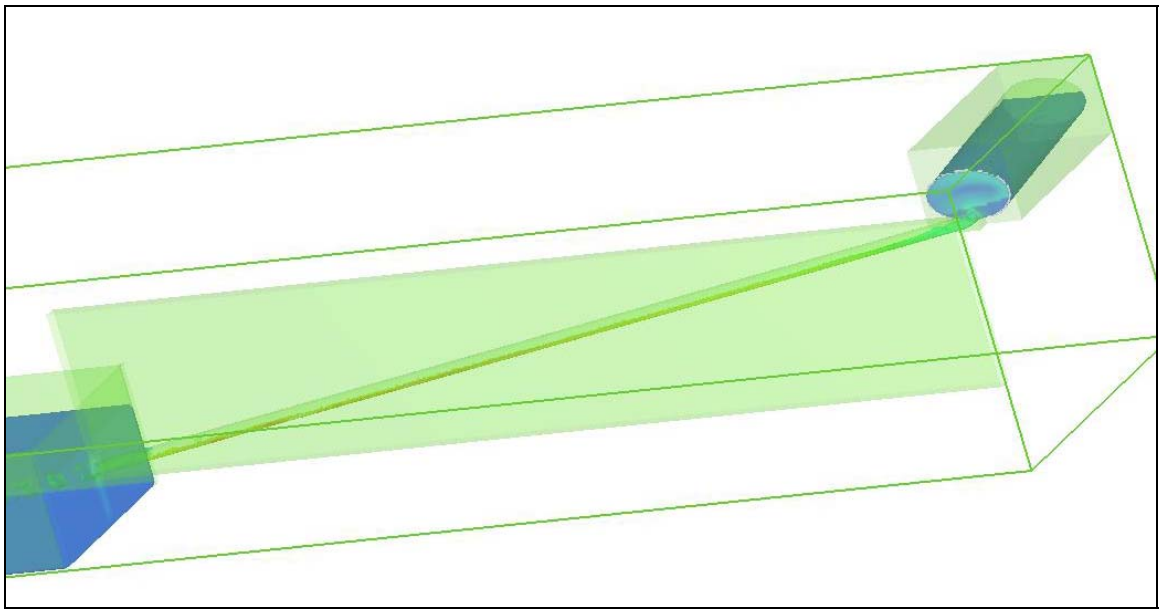


Figure 23 – View showing the CFD model of the model fish release facility.

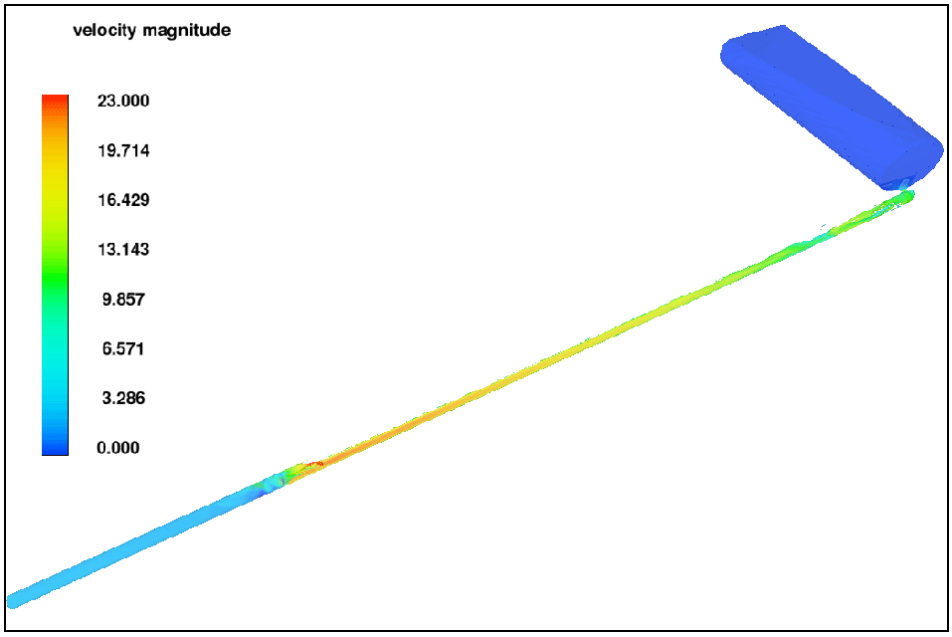


Figure 24 – Numerical simulation of flow velocity (ft/s) in release pipe for stepped operation 5 sec after gate is opened. Gate 40 percent open.

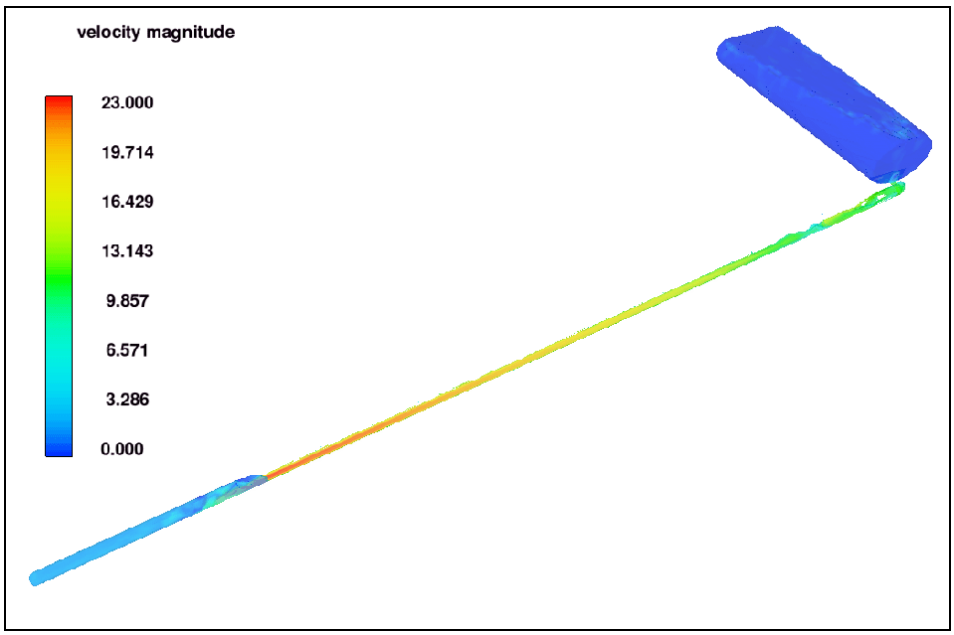


Figure 25 – Numerical simulation of flow velocity (ft/s) in release pipe for stepped operation 20 sec after gate is opened. Gate 50 percent open.

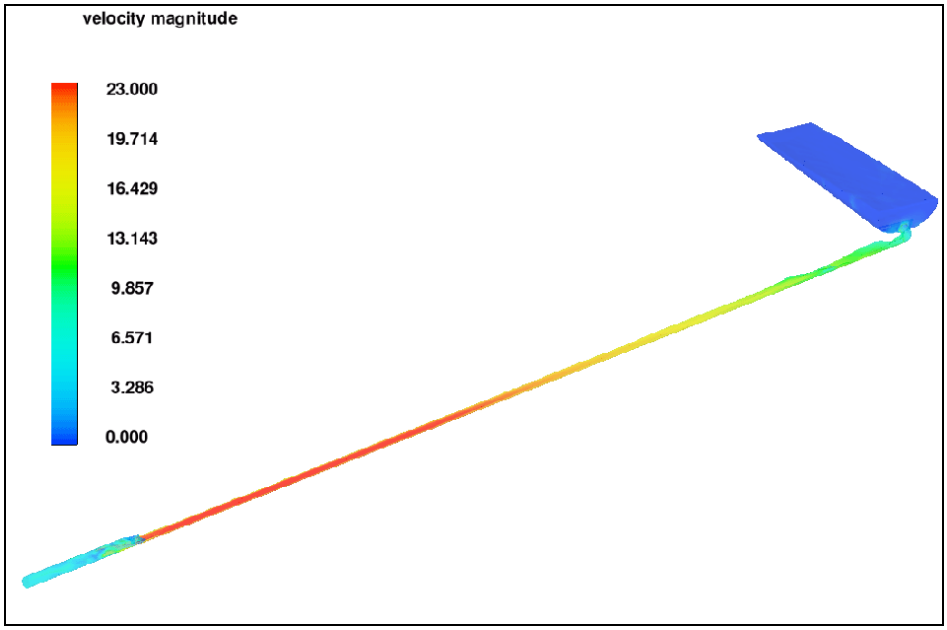


Figure 26 - Numerical simulation of flow velocity (ft/s) in release pipe for stepped operation 60 sec after gate is opened. Gate 100 percent open.

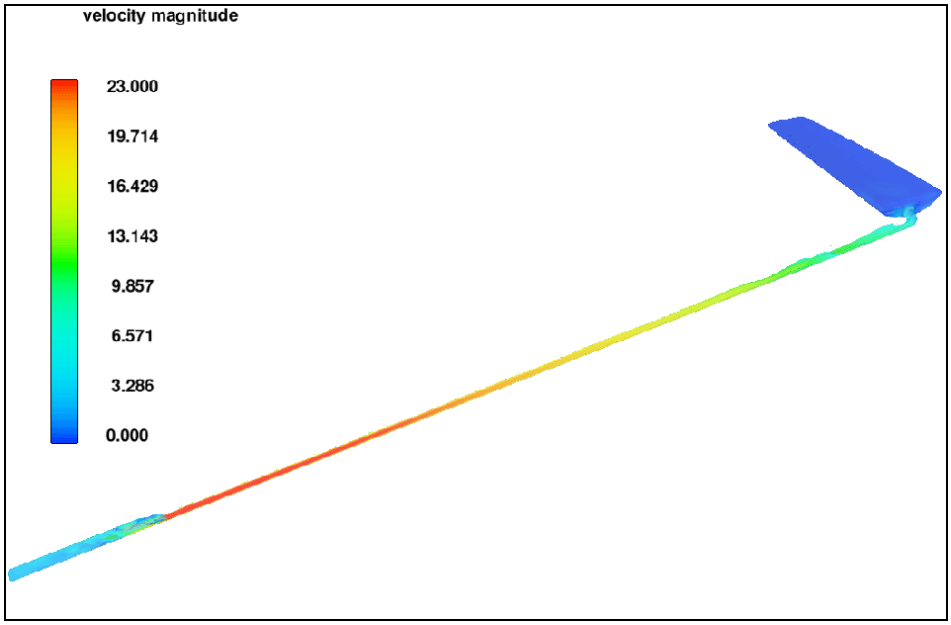


Figure 27 - Numerical simulation of flow velocity (ft/s) in release pipe for stepped operation 90 sec after gate is opened. Gate 100 percent open.

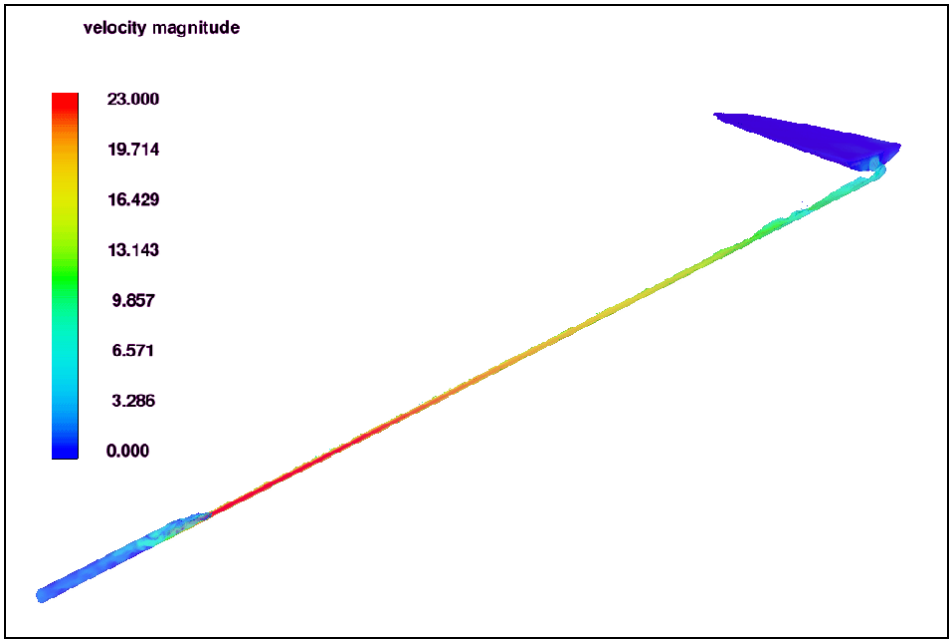


Figure 28 - Numerical simulation of flow velocity (ft/s) in release pipe for stepped operation 110 sec after gate is opened. Gate 100 percent open.

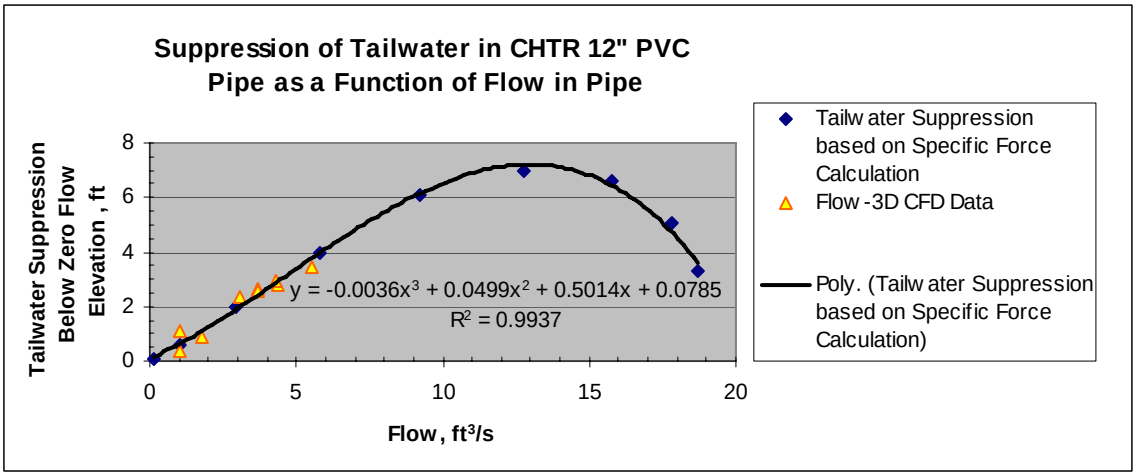


Figure 29 - Comparison of hydraulic jump suppression determined by CFD model and specific force calculation.

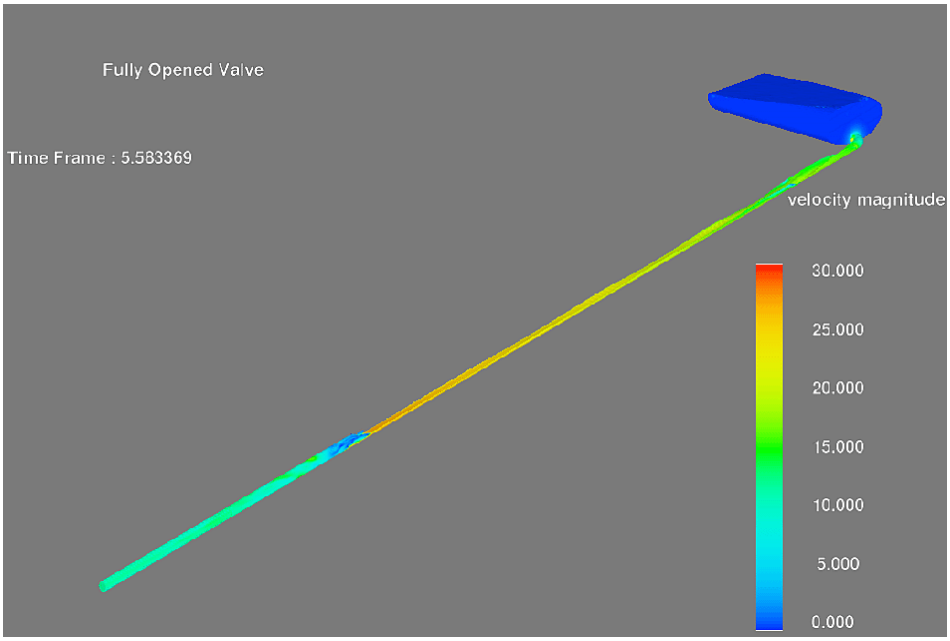


Figure 30 - Numerical simulation of flow velocity (ft/s) in release pipe for full open gate operation 5 sec after gate is opened. Gate 100 percent open

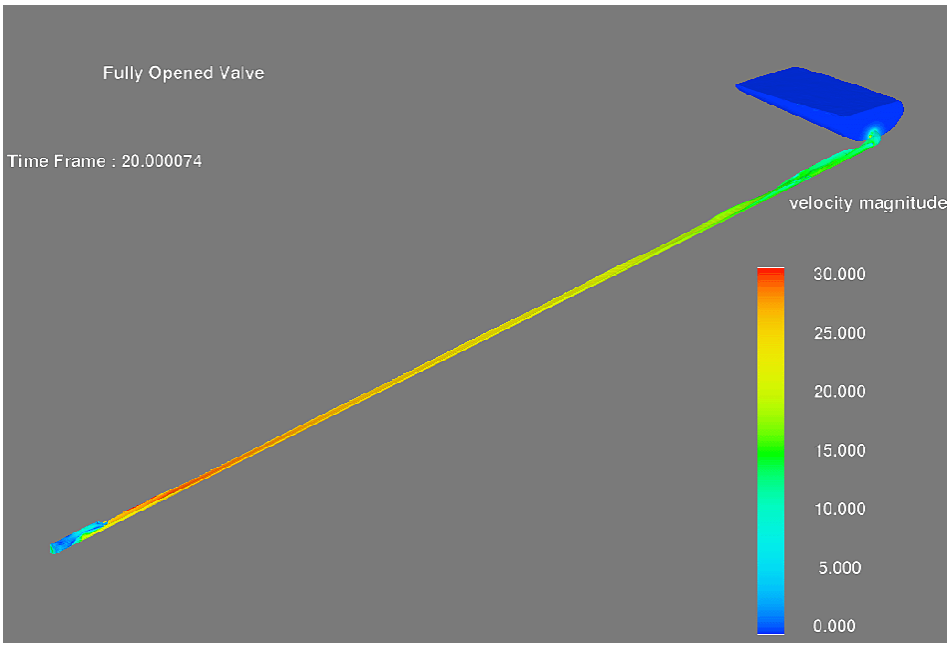


Figure 31 - Numerical simulation of flow velocity (ft/s) in release pipe for full open gate operation 20 sec after gate is opened. Gate 100 percent open.

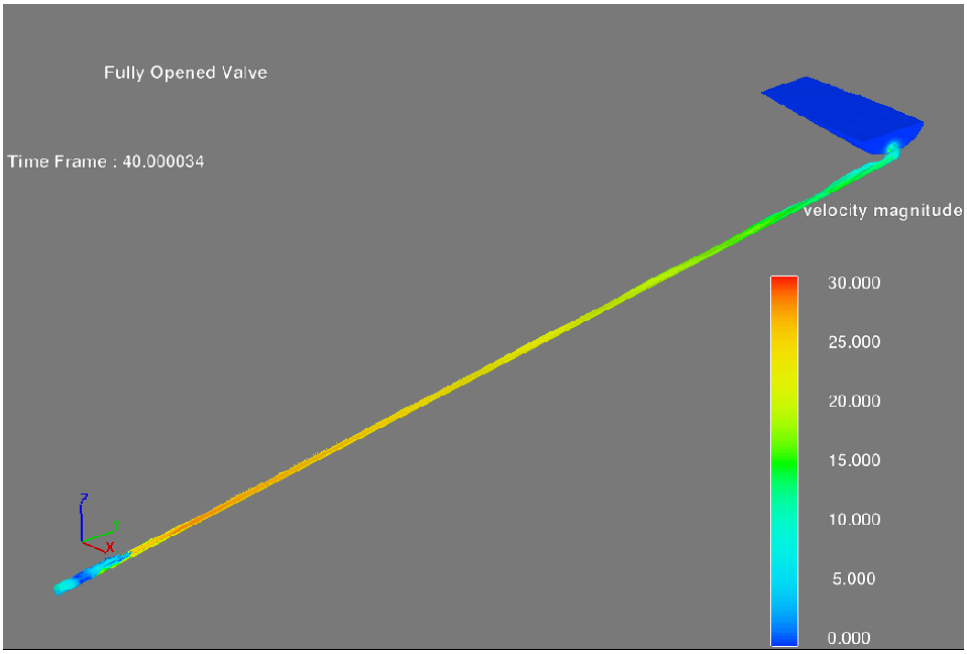


Figure 32 - Numerical simulation of flow velocity (ft/s) in release pipe for full open gate operation 40 sec after gate is opened. Gate 100 percent open.

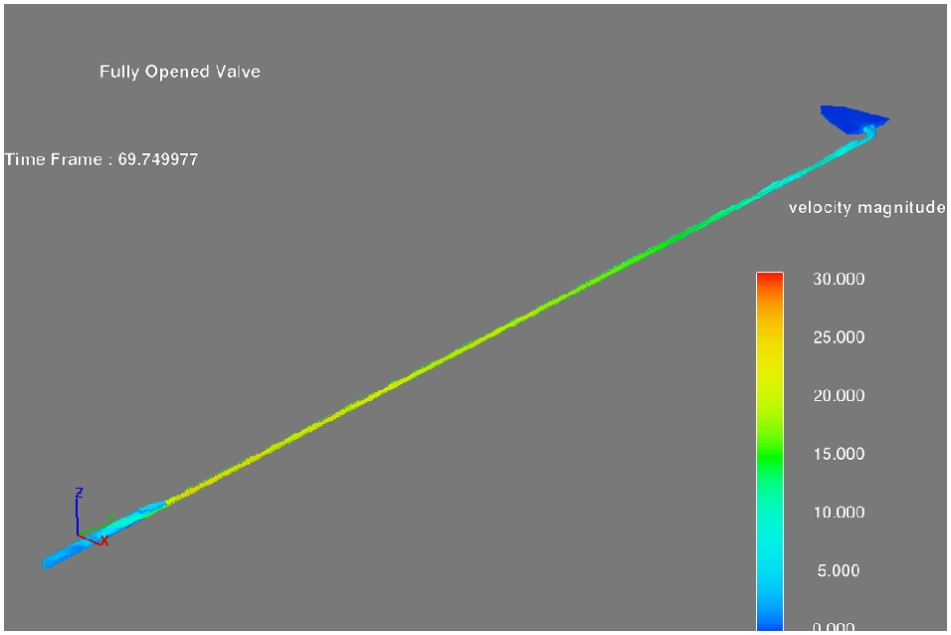


Figure 33 - Numerical simulation of flow velocity (ft/s) in release pipe for full open gate operation 70 sec after gate is opened. Gate 100 percent open.

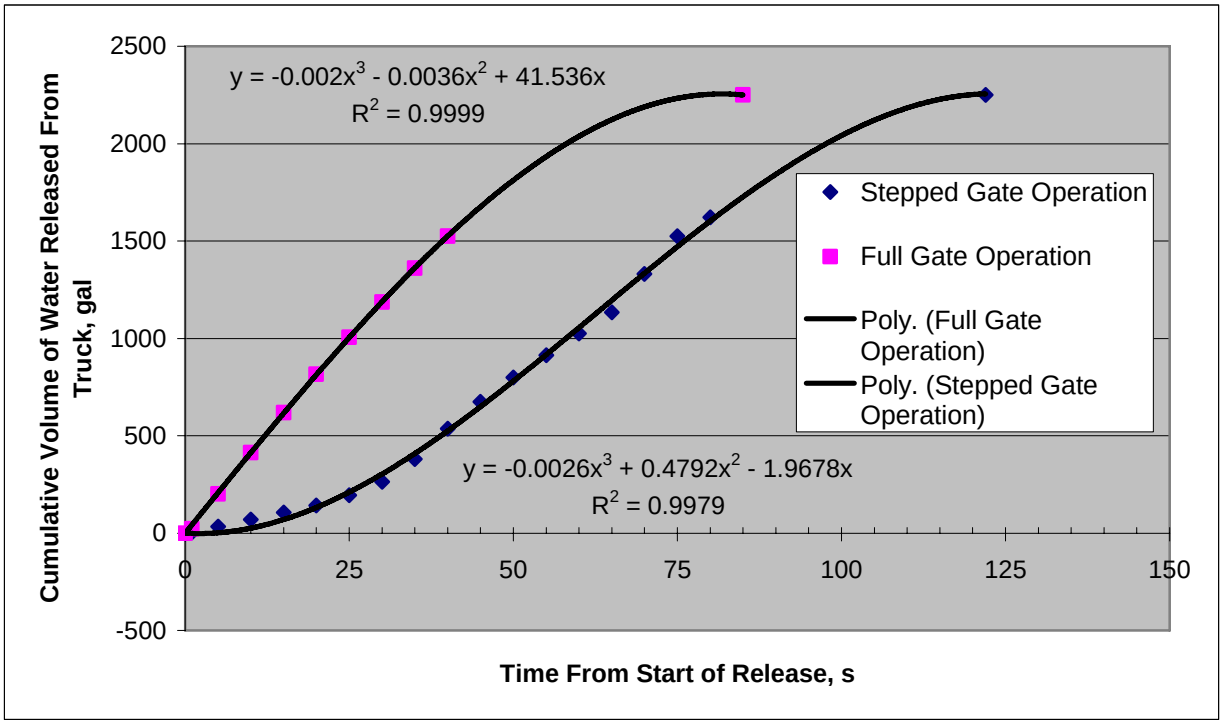
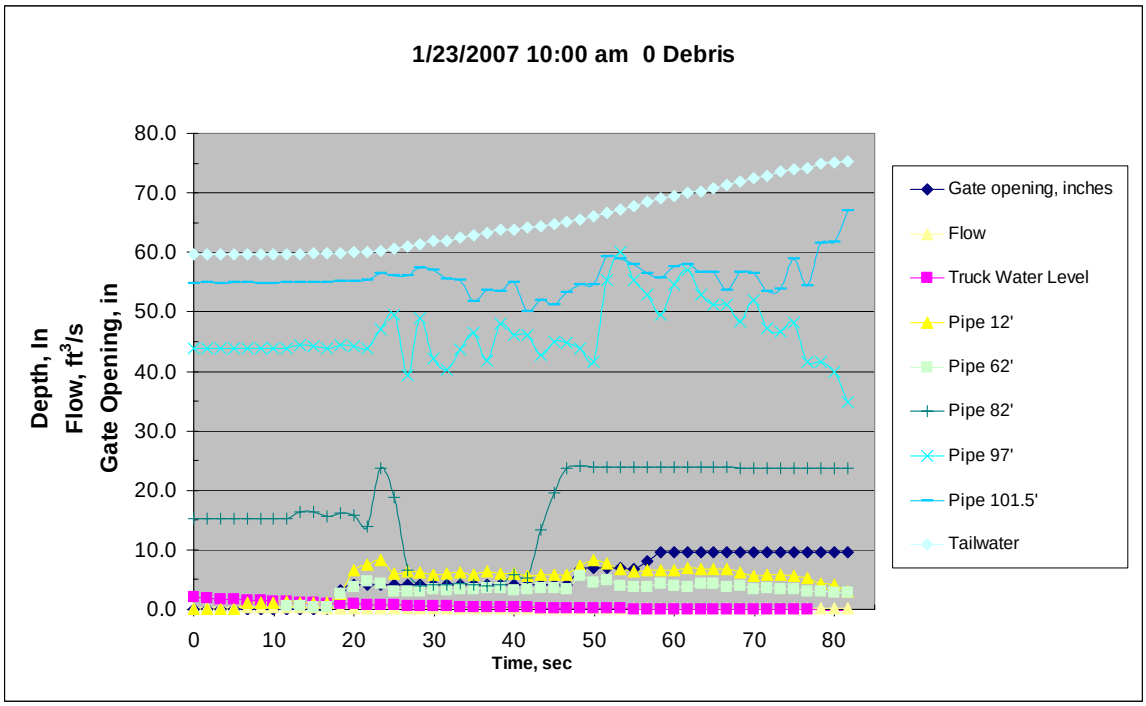
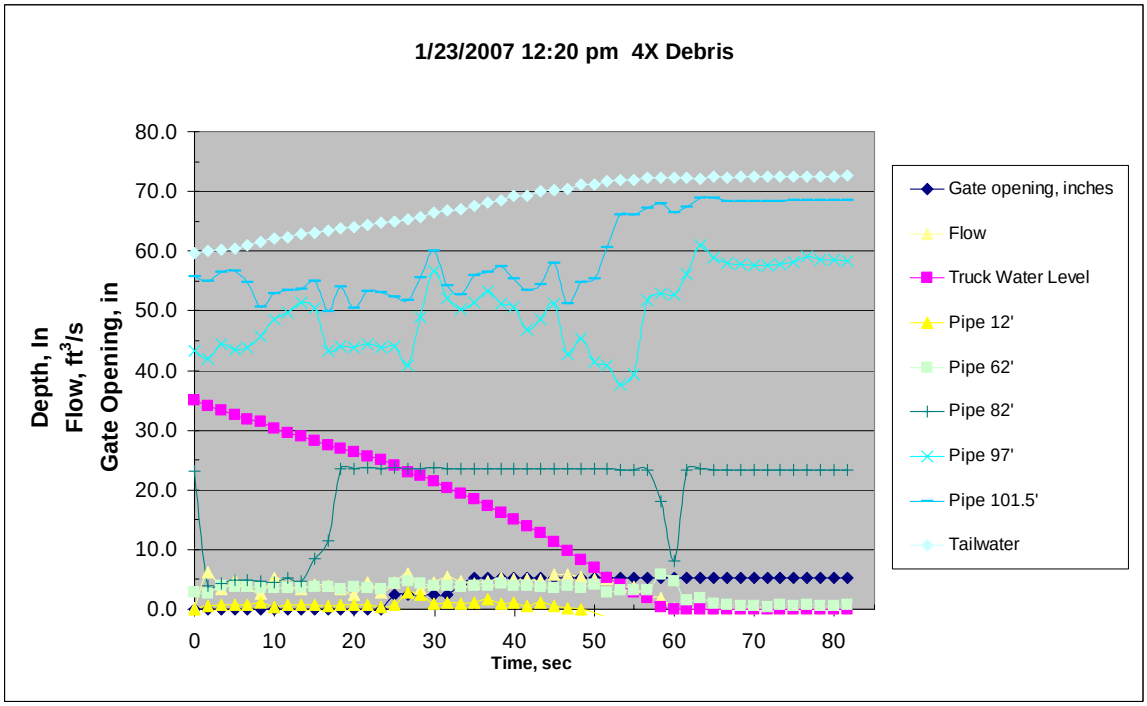
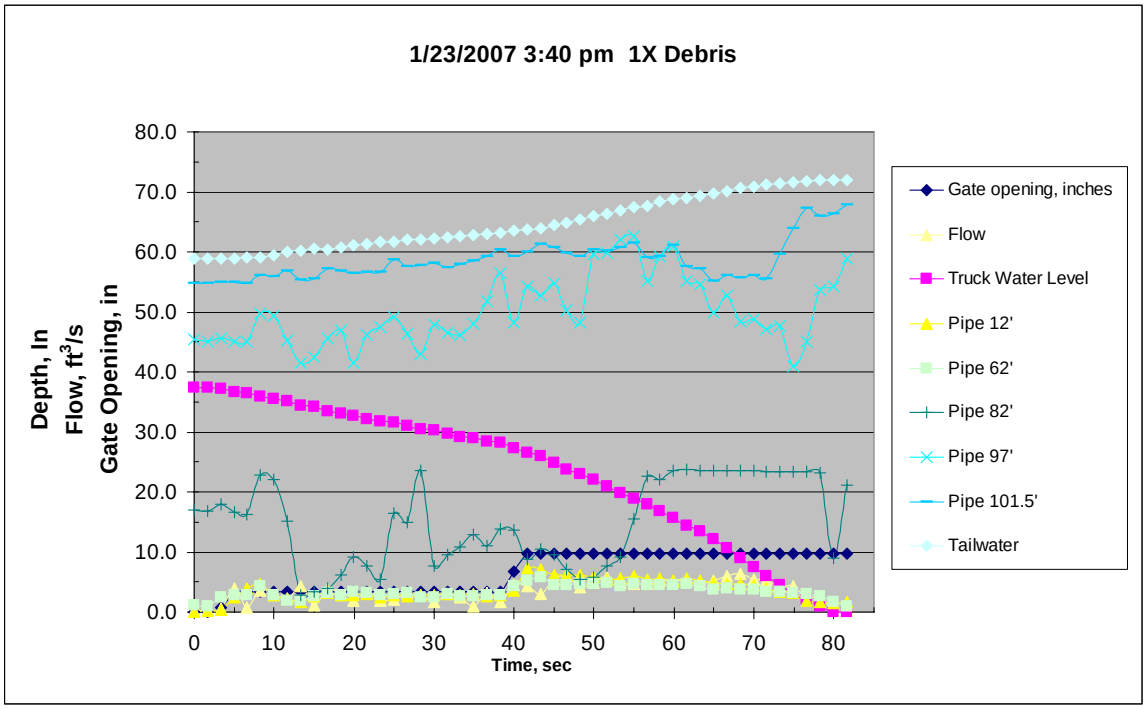


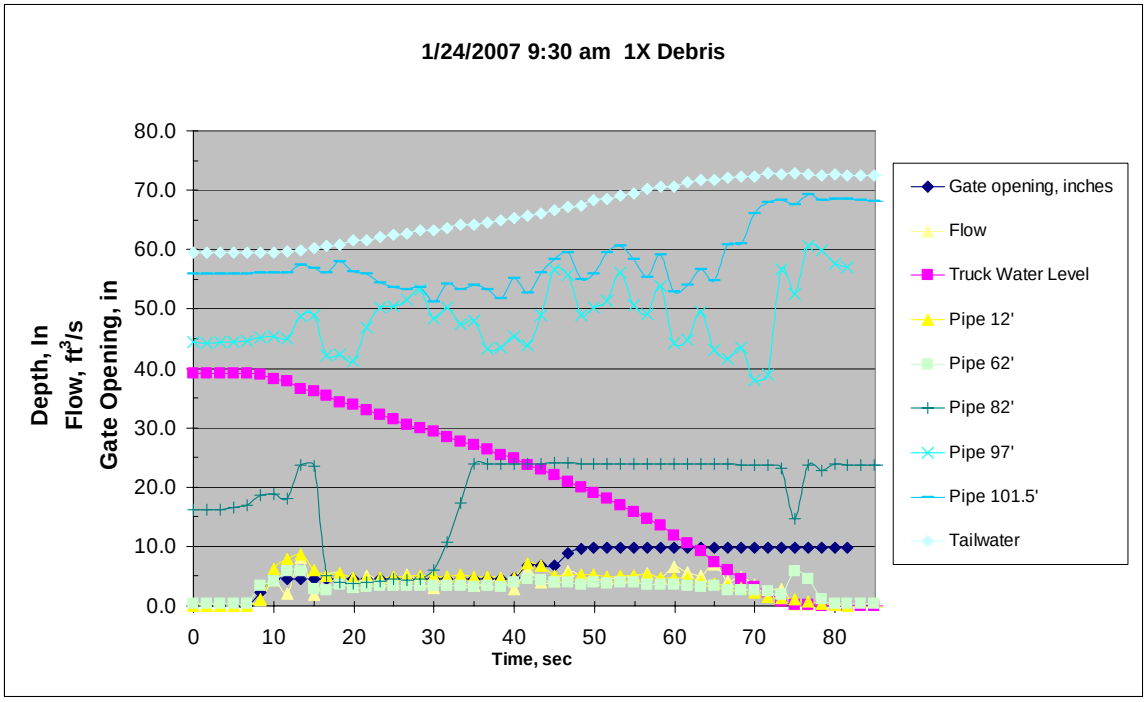
Figure 34 – CFD comparison of fish tank flow release for a typical stepped gate operation and a rapid fully opened gate operation.

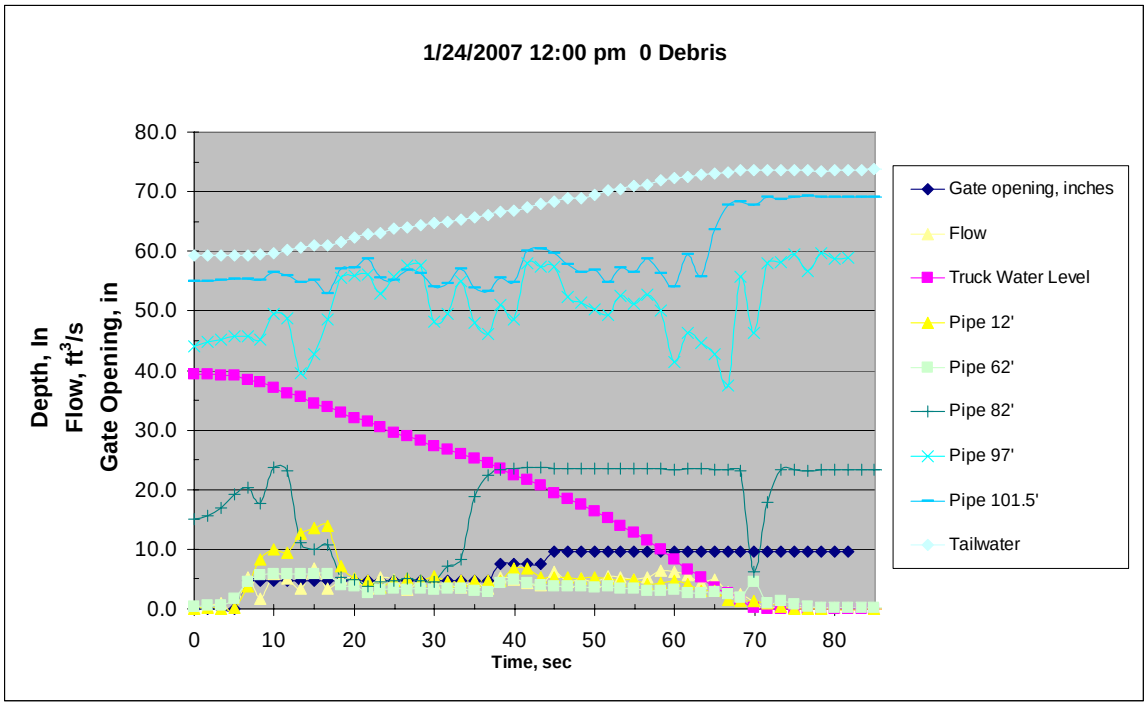
APPENDIX - Model Test Hydraulic Data

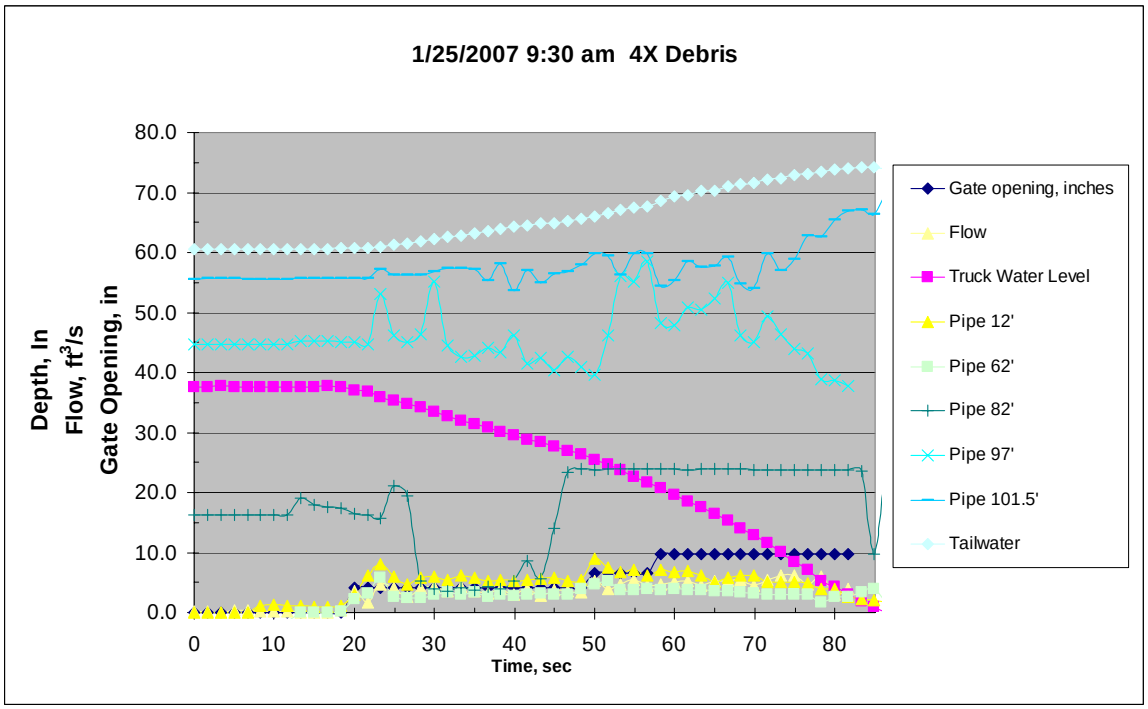


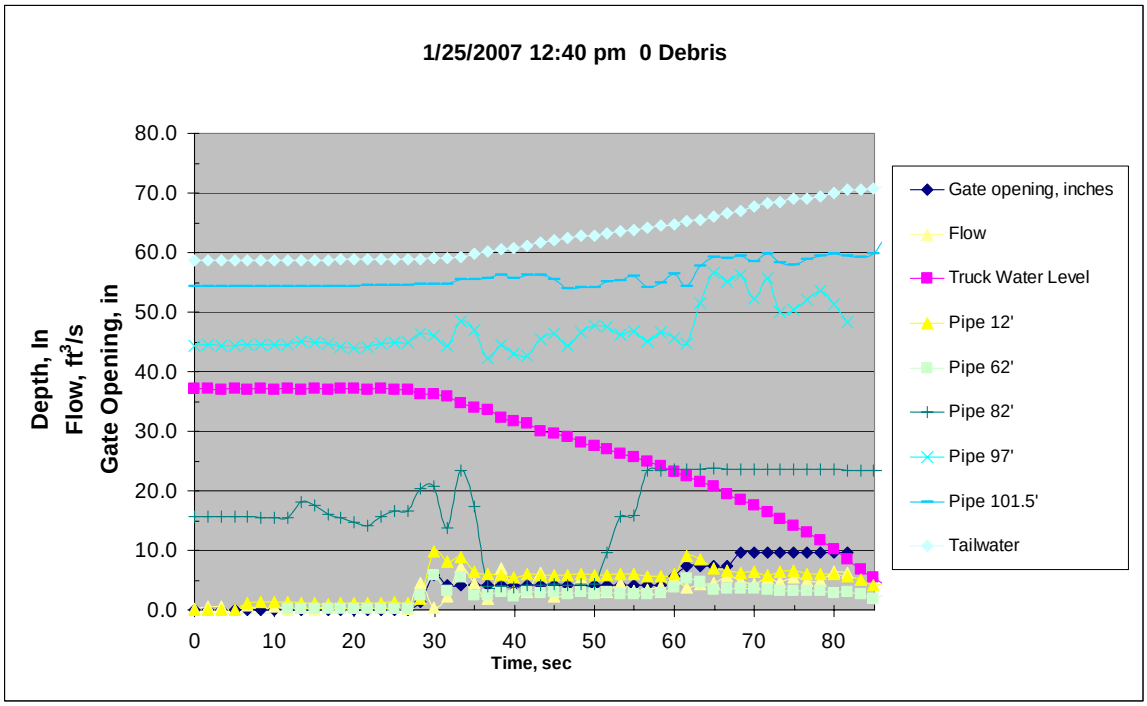


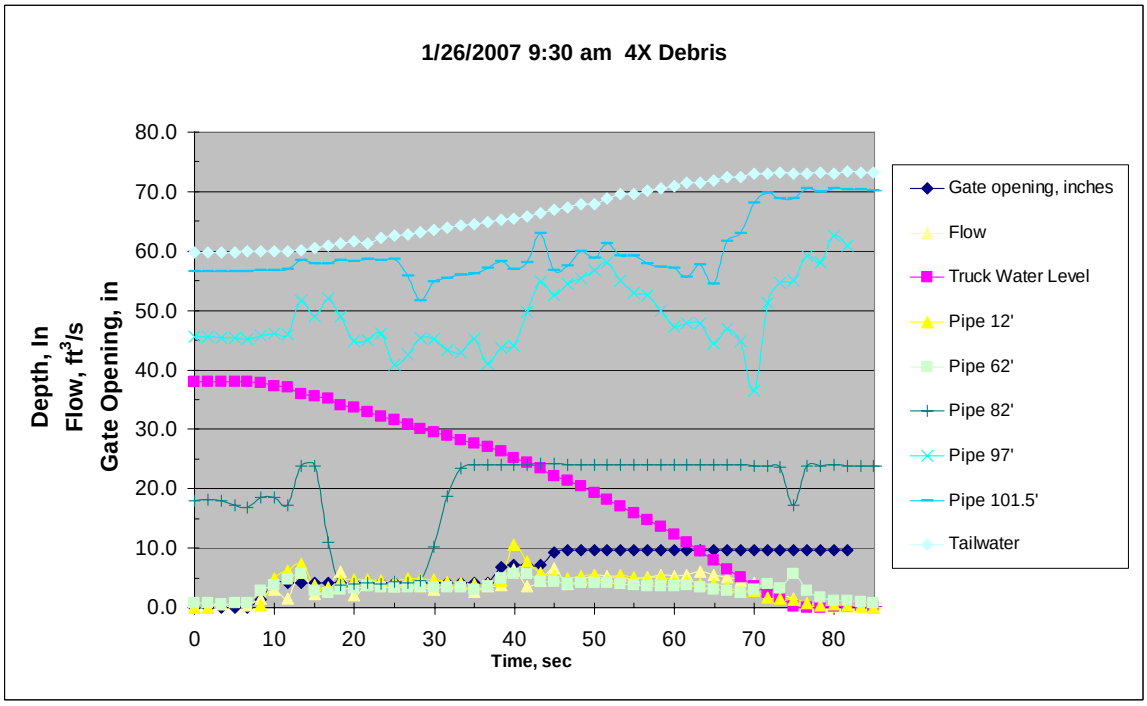

1/23/2007 3:40 pm 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

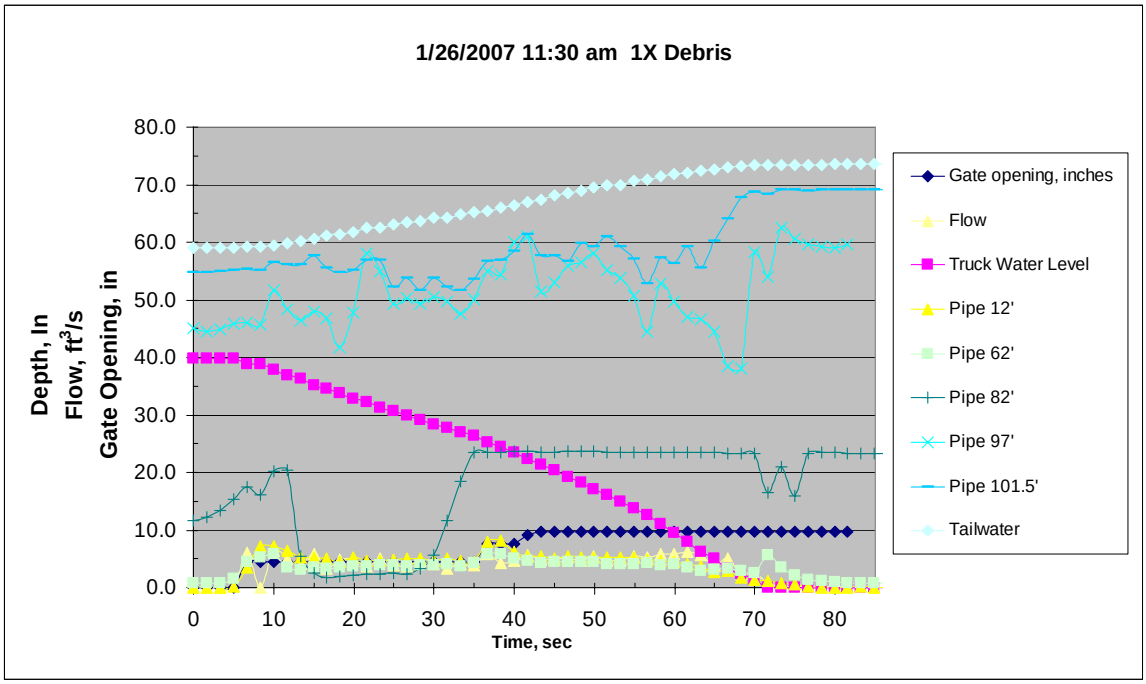

1/24/2007 9:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

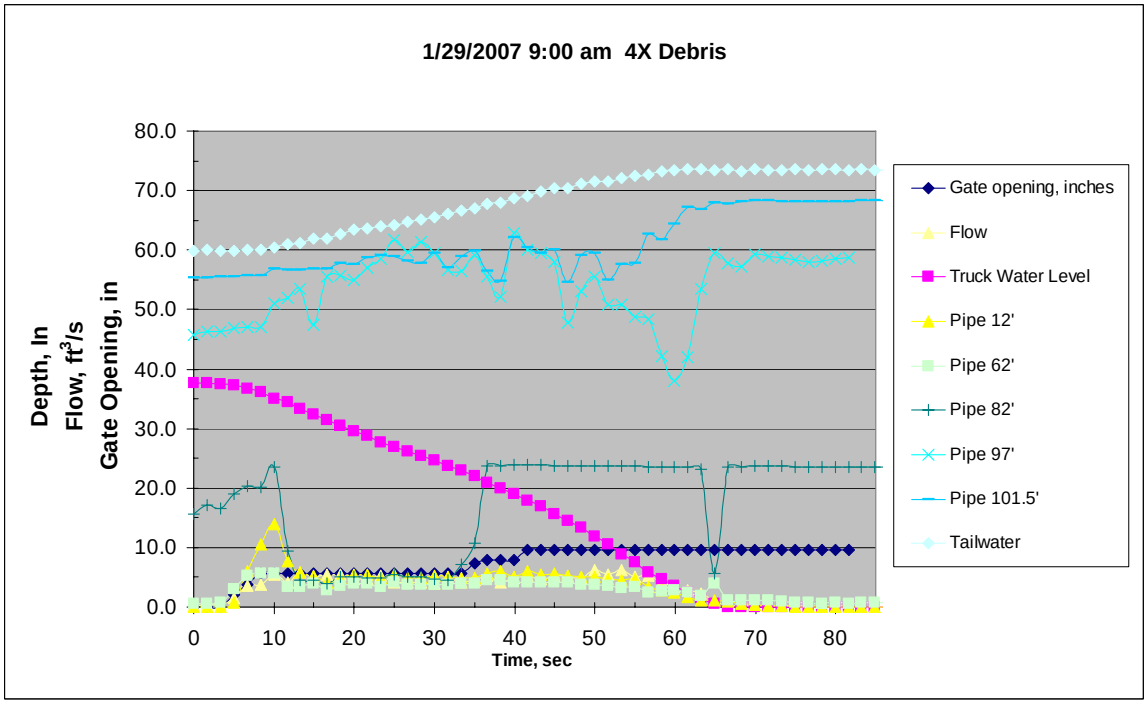

1/24/2007 12:00 pm 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

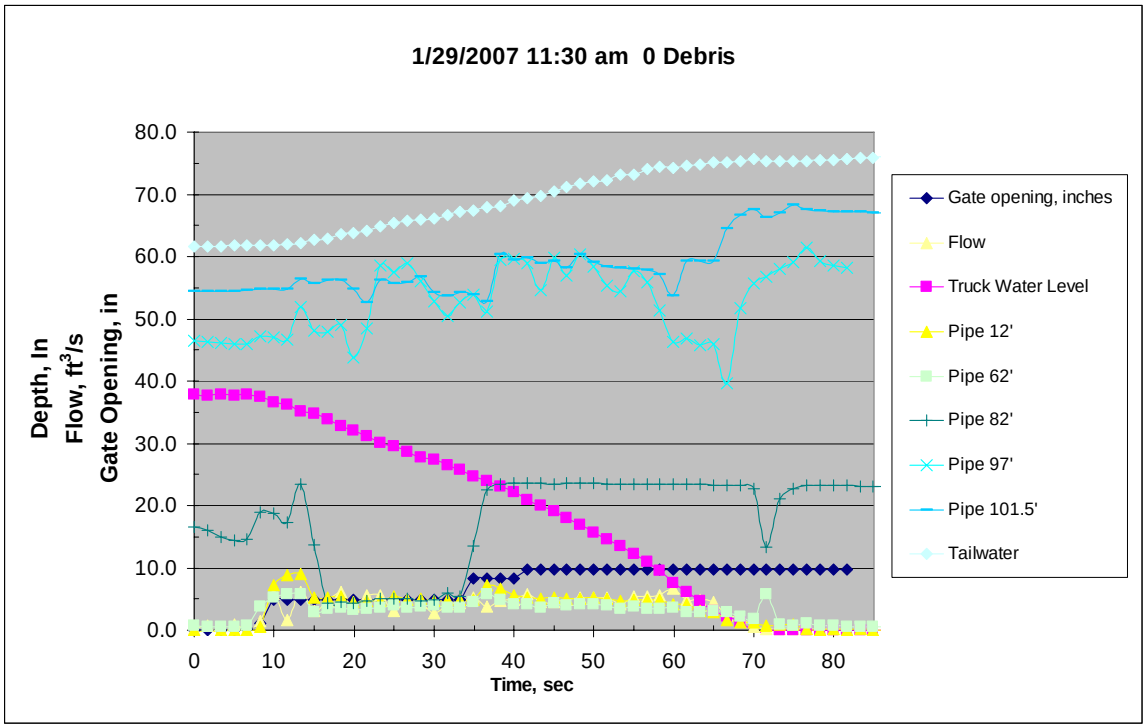

1/25/2007 9:30 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

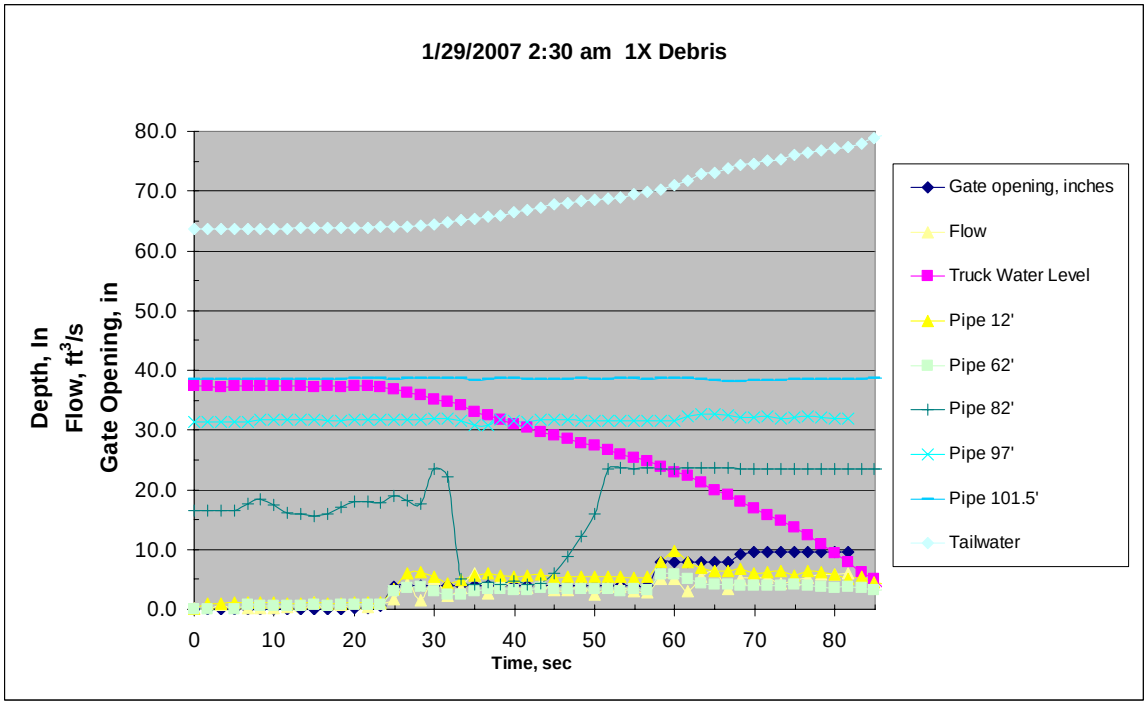

1/25/2007 12:40 pm 0 Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

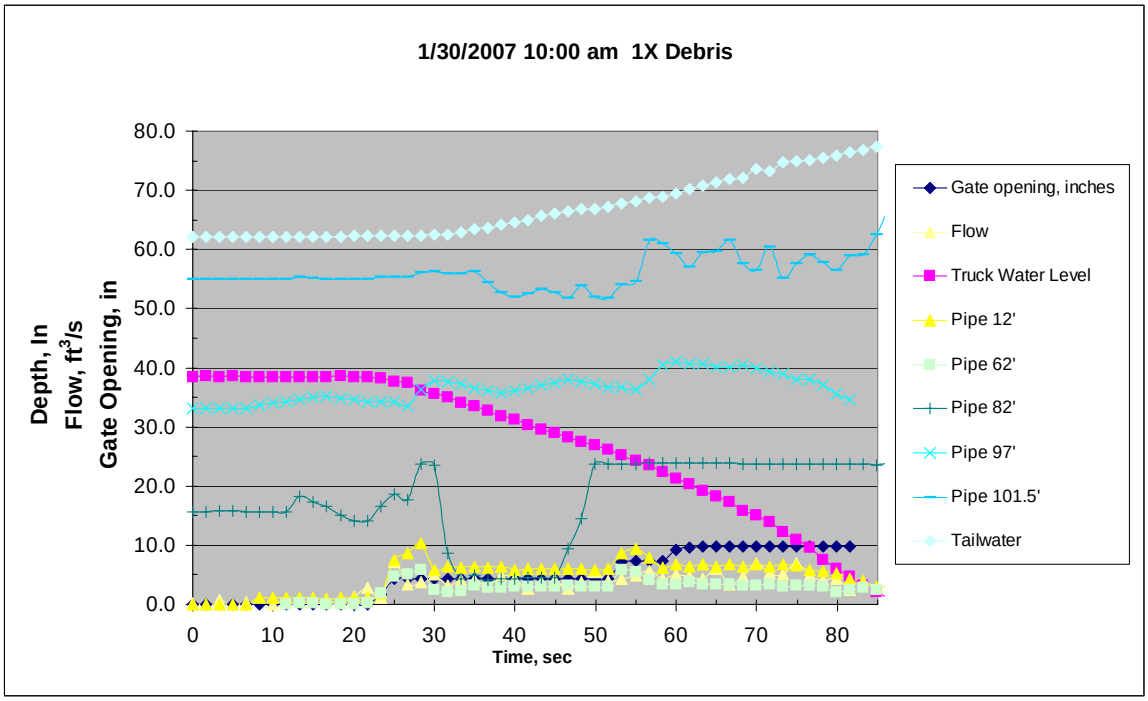

1/26/2007 9:30 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

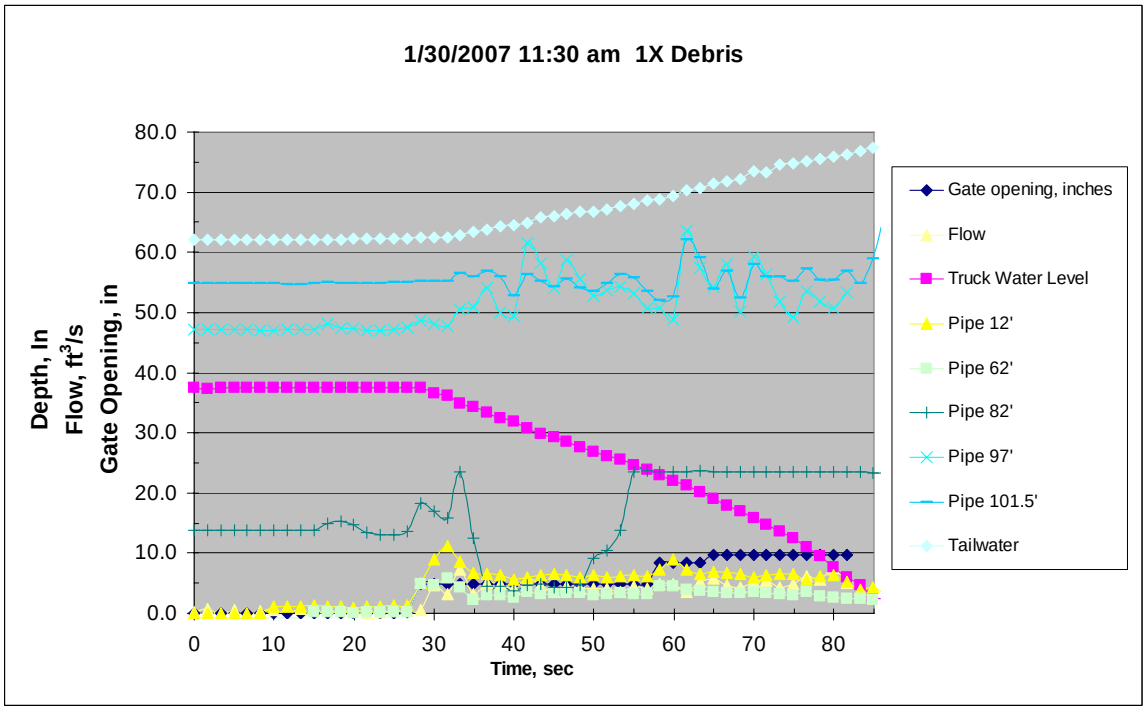

1/26/2007 11:30 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

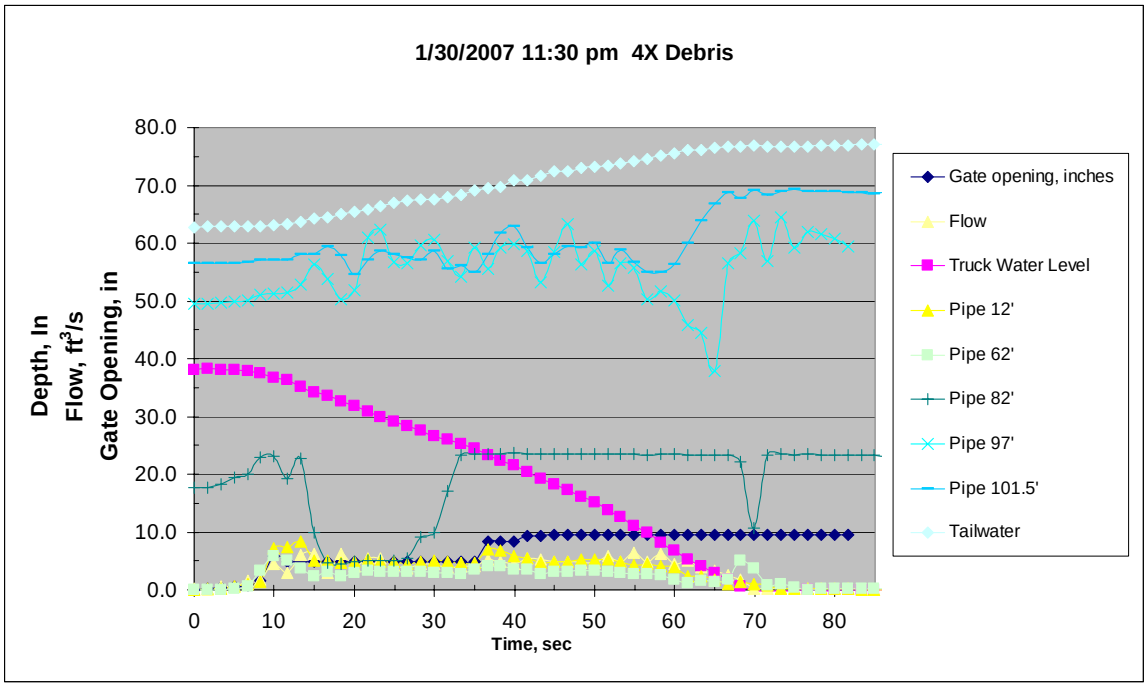

1/29/2007 9:00 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

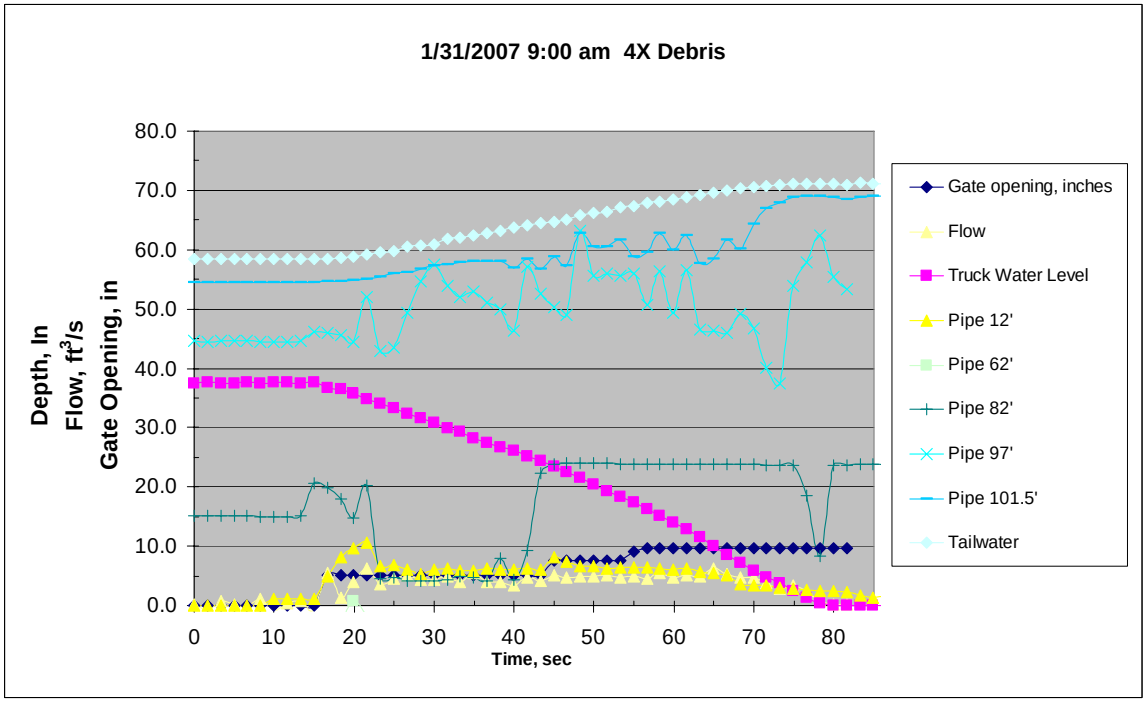

1/29/2007 11:30 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

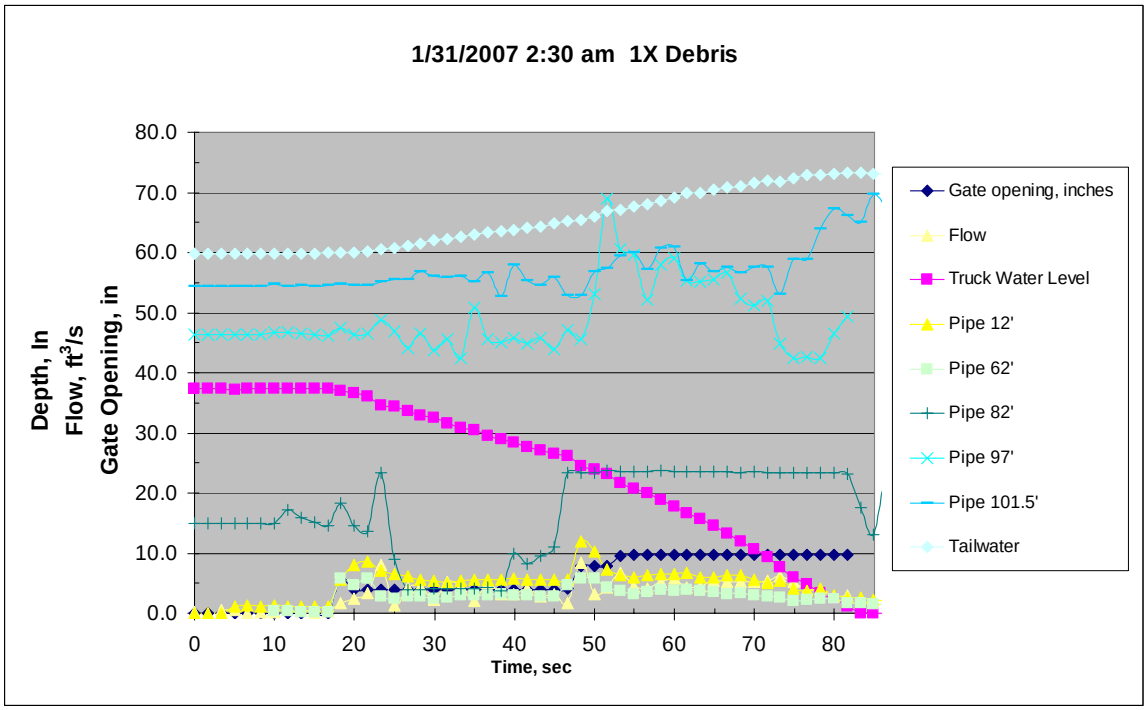

1/29/2007 2:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

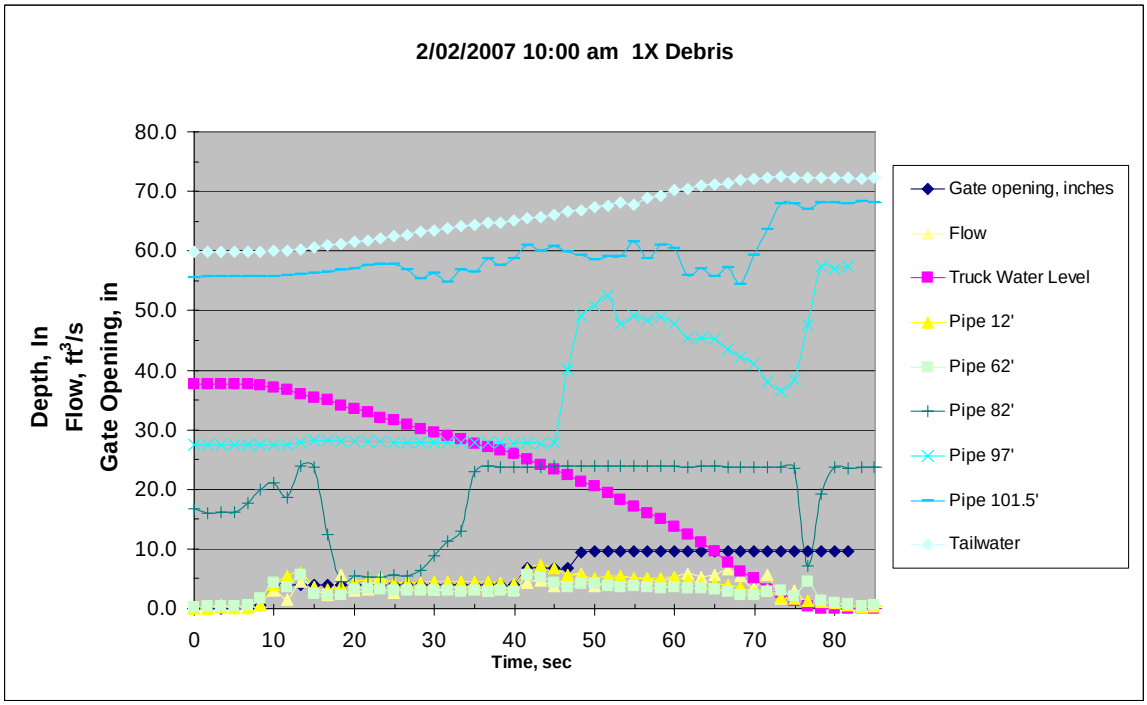

1/30/2007 10:00 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

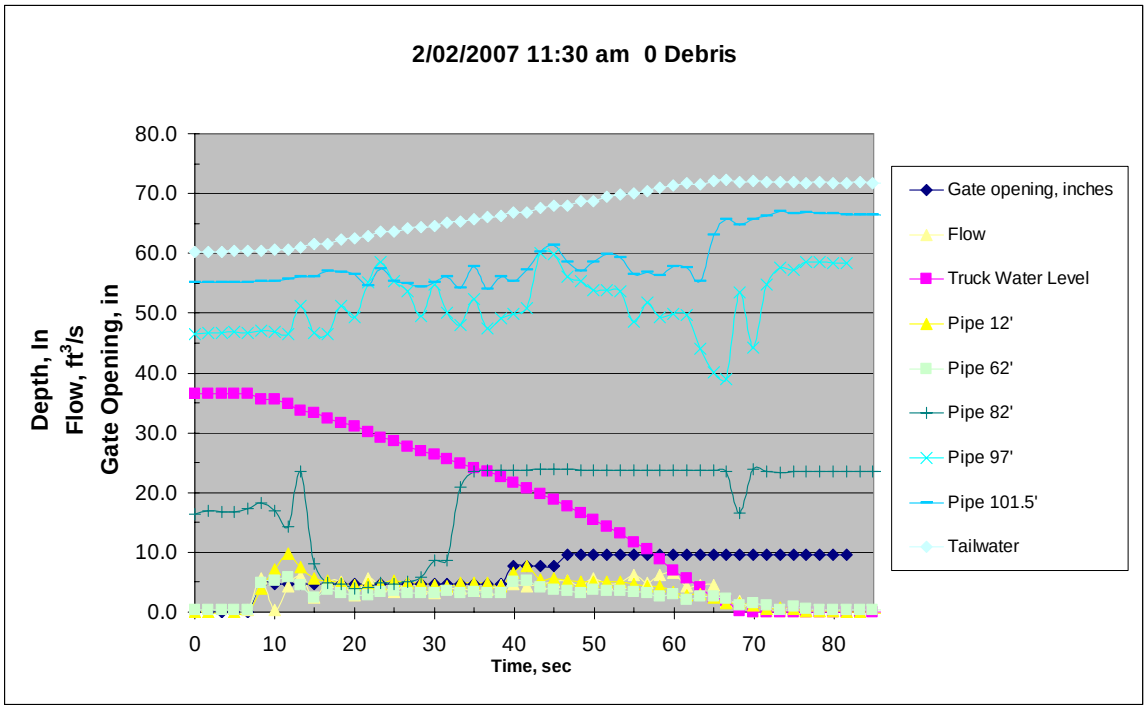

1/30/2007 11:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

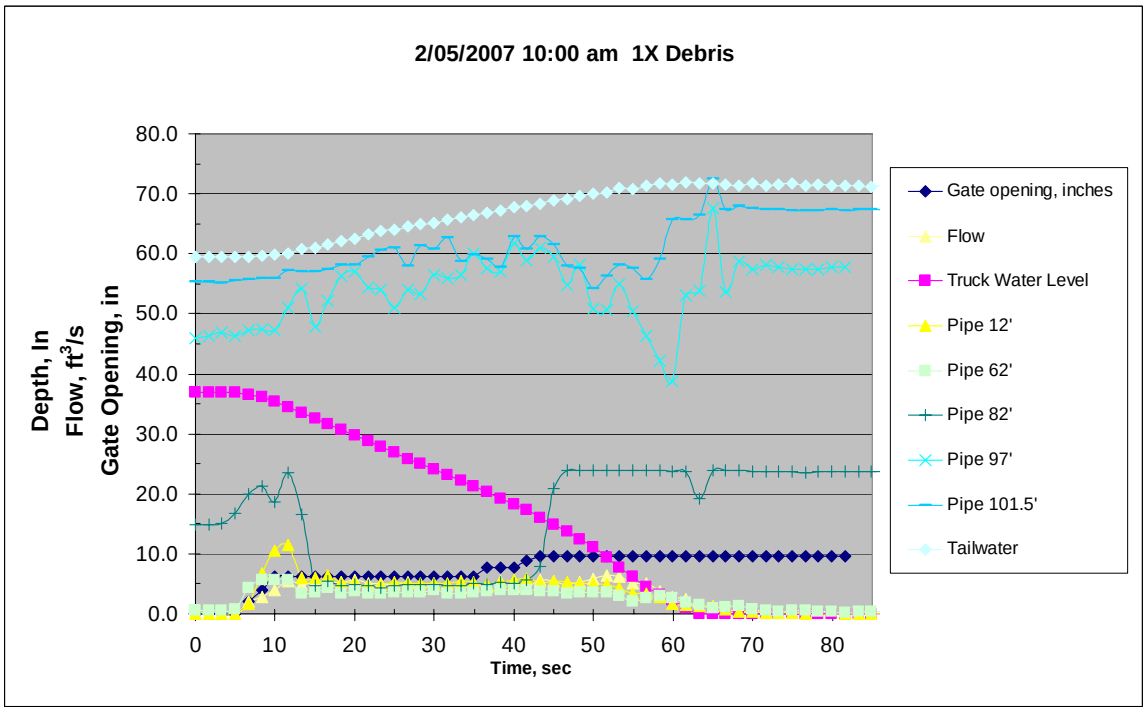

1/30/2007 11:30 pm 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

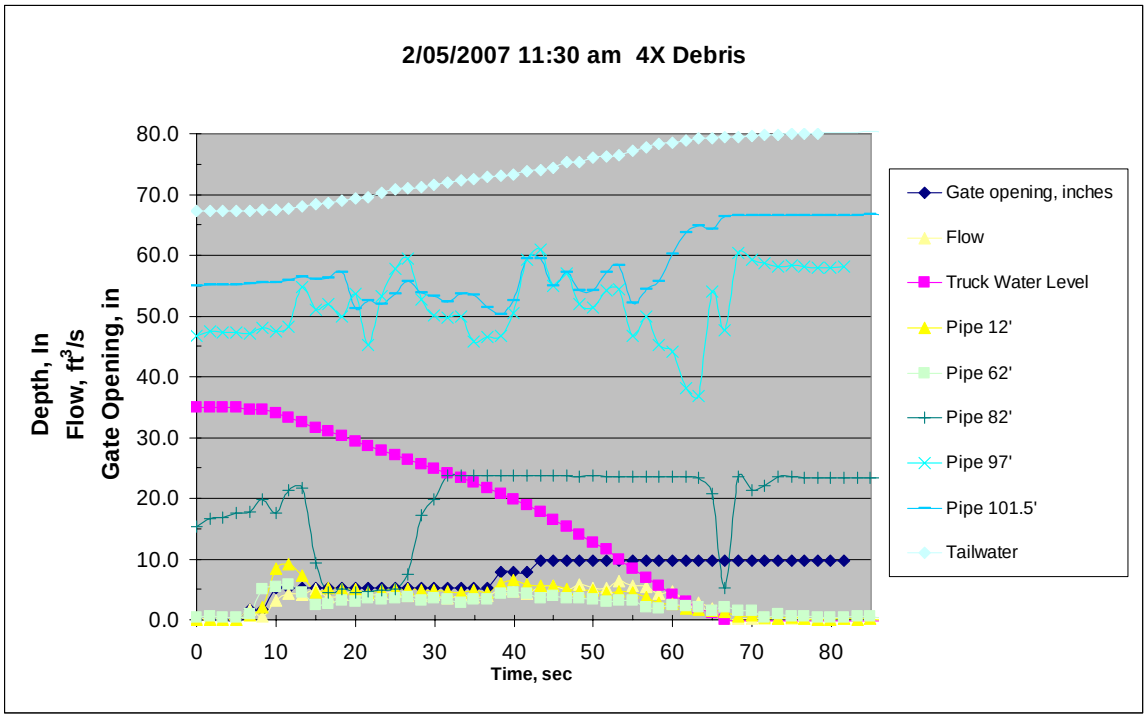

1/31/2007 9:00 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

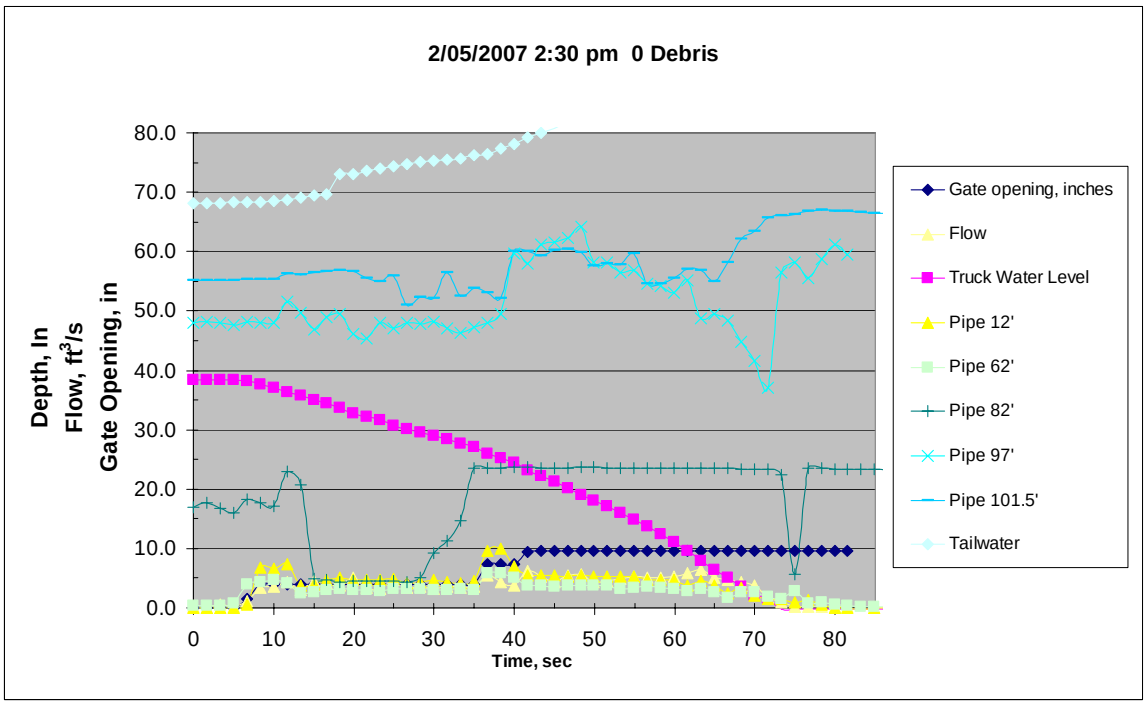

1/31/2007 2:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

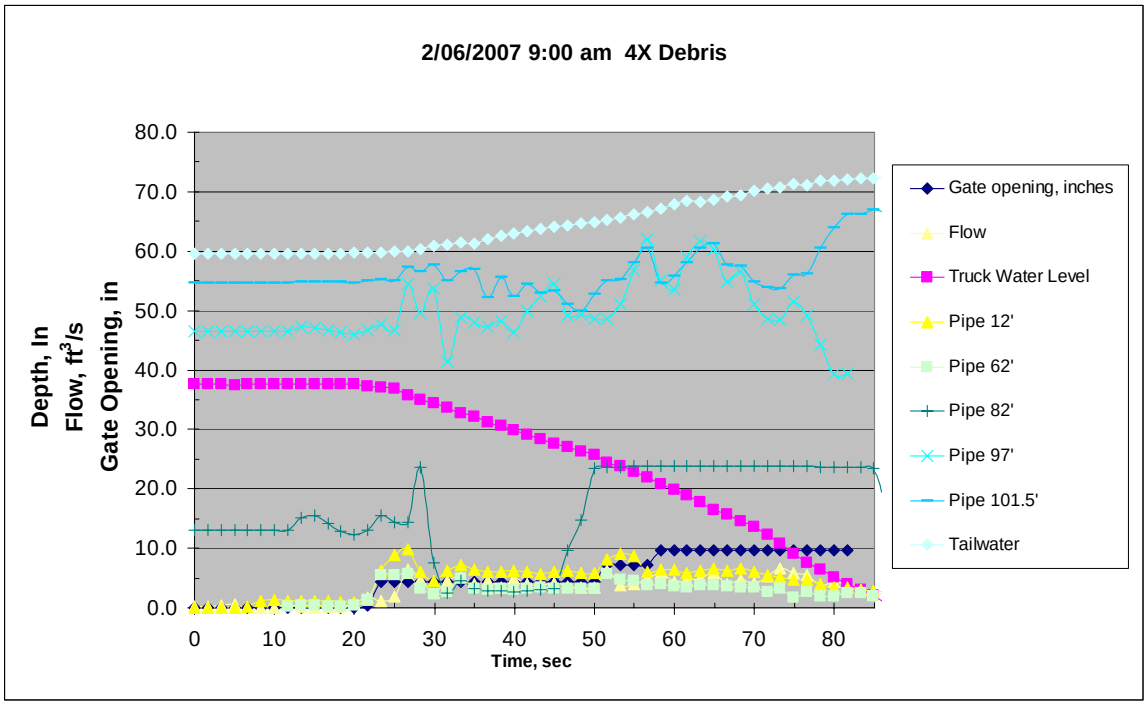

2/02/2007 10:00 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

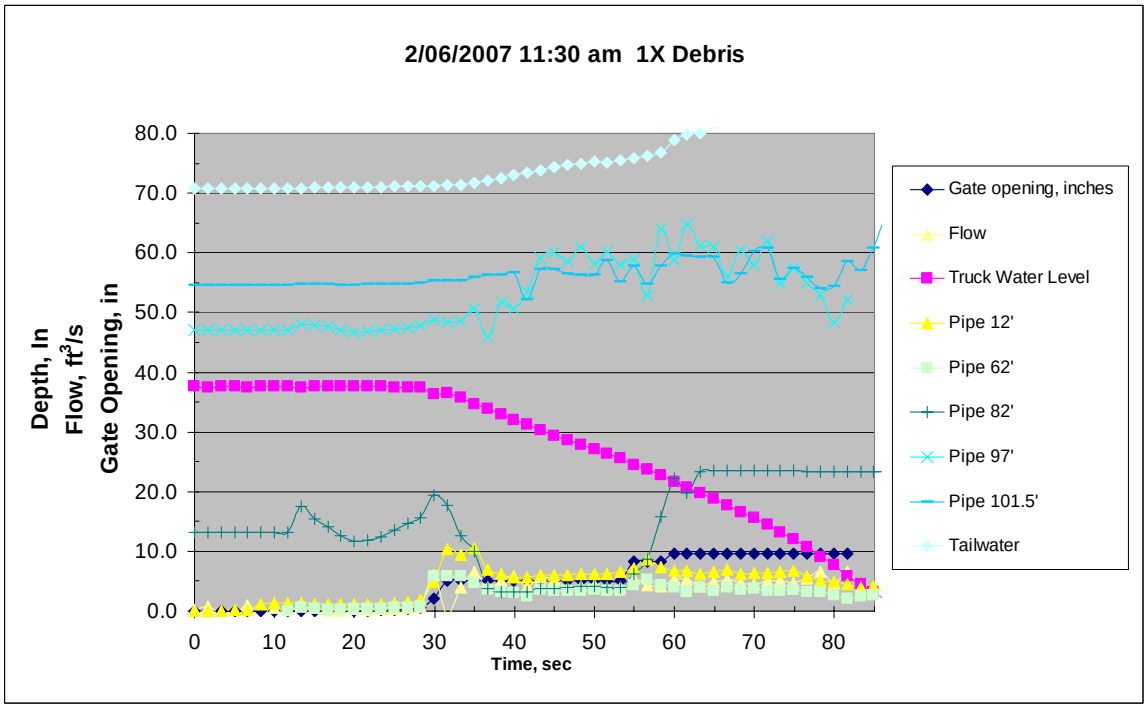

2/02/2007 11:30 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

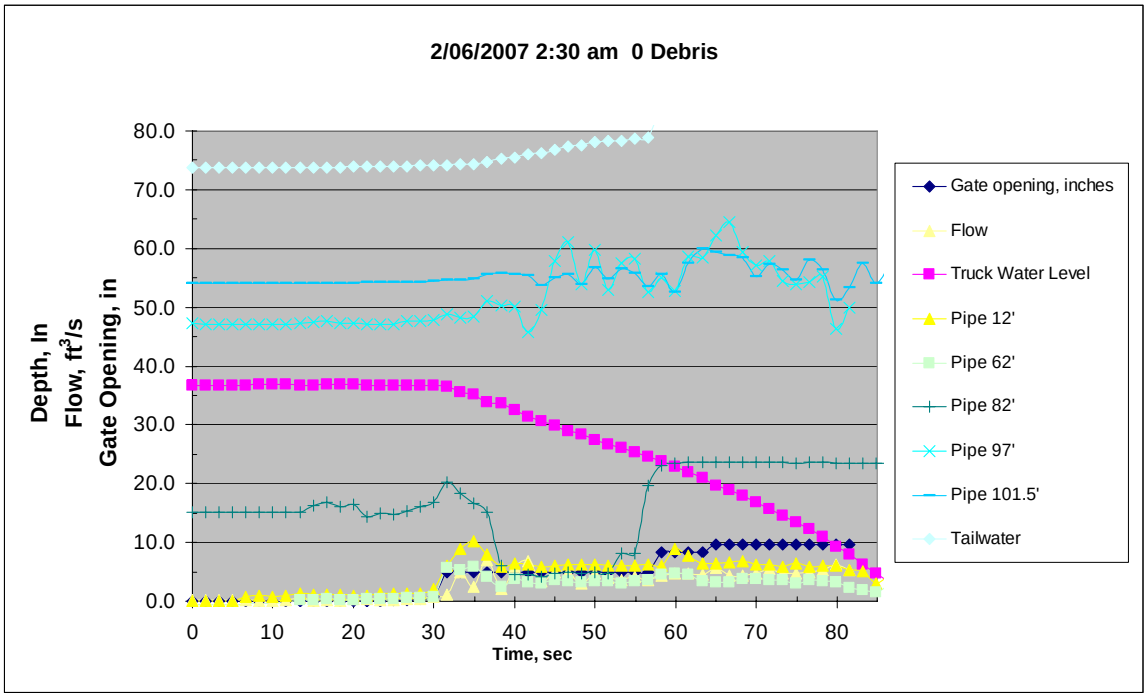

2/05/2007 10:00 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

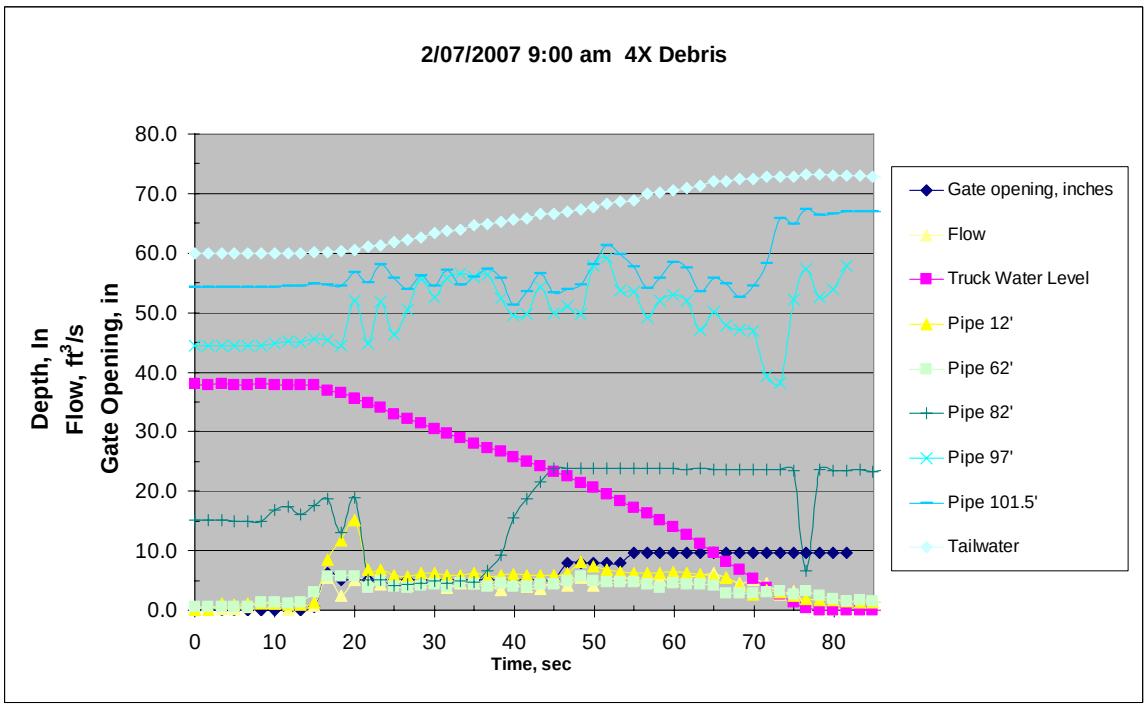

2/05/2007 11:30 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

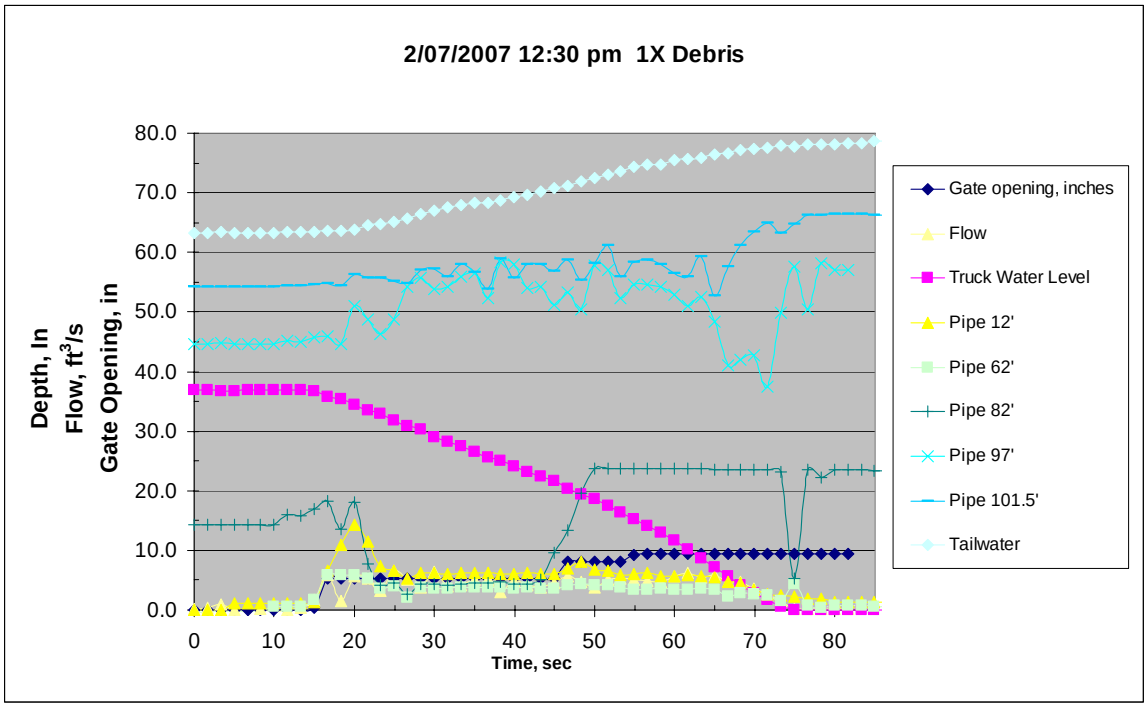

2/05/2007 2:30 pm 0 Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

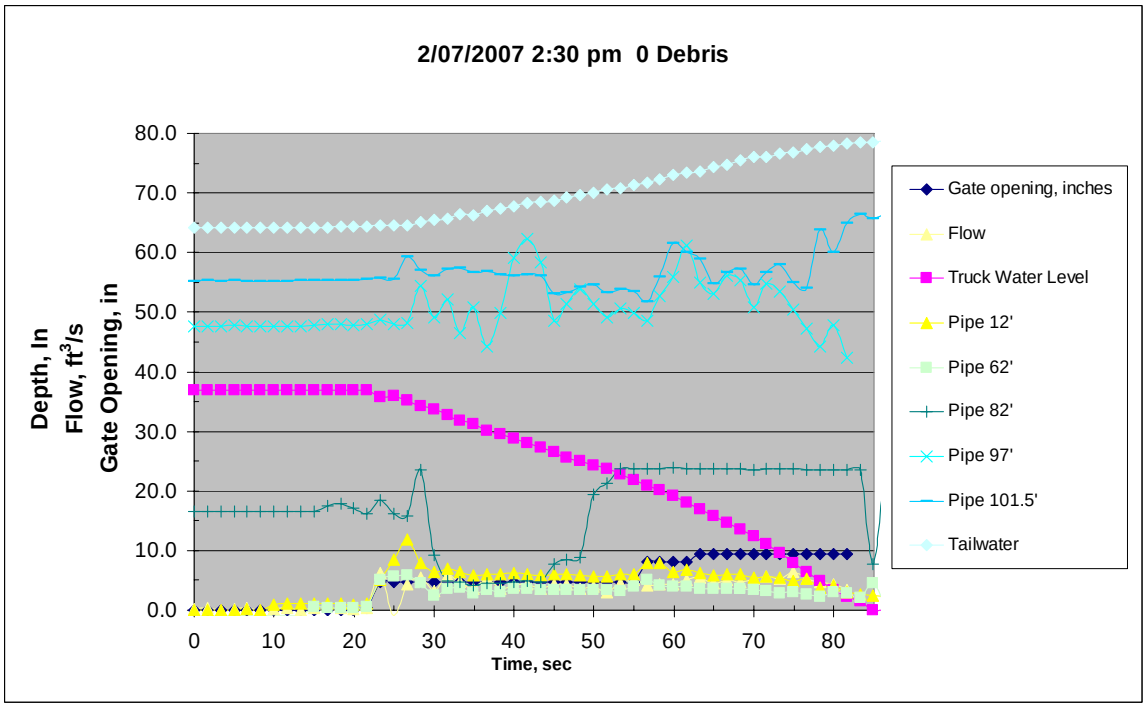

2/06/2007 9:00 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

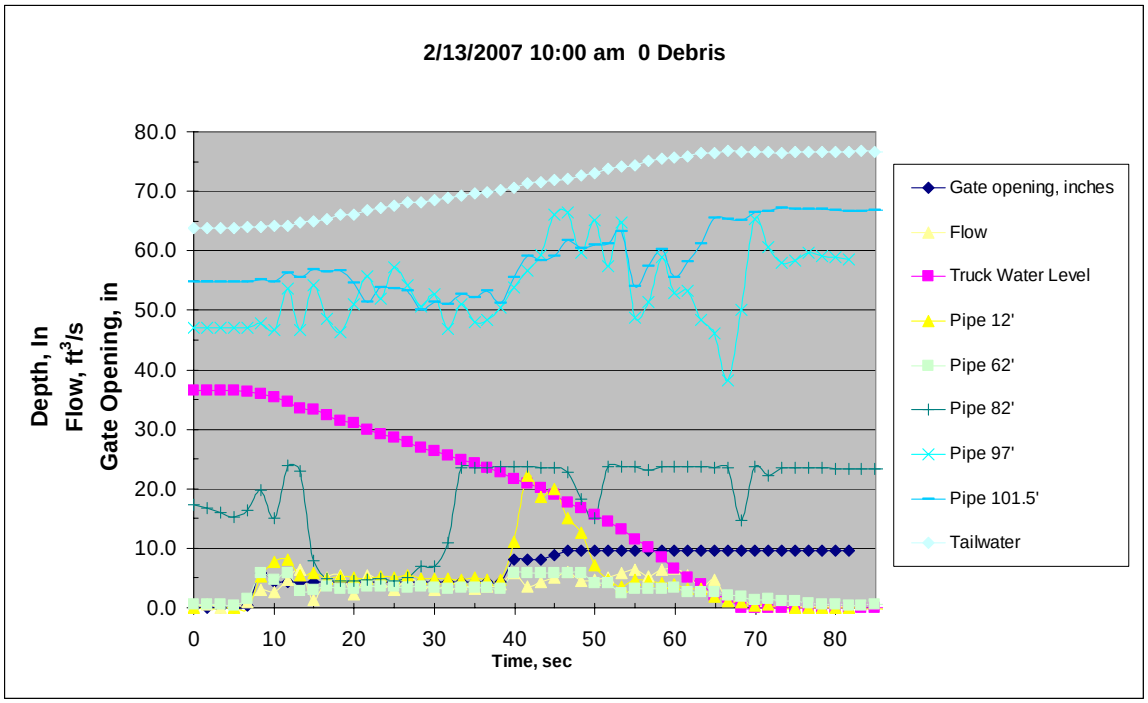

2/06/2007 11:30 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

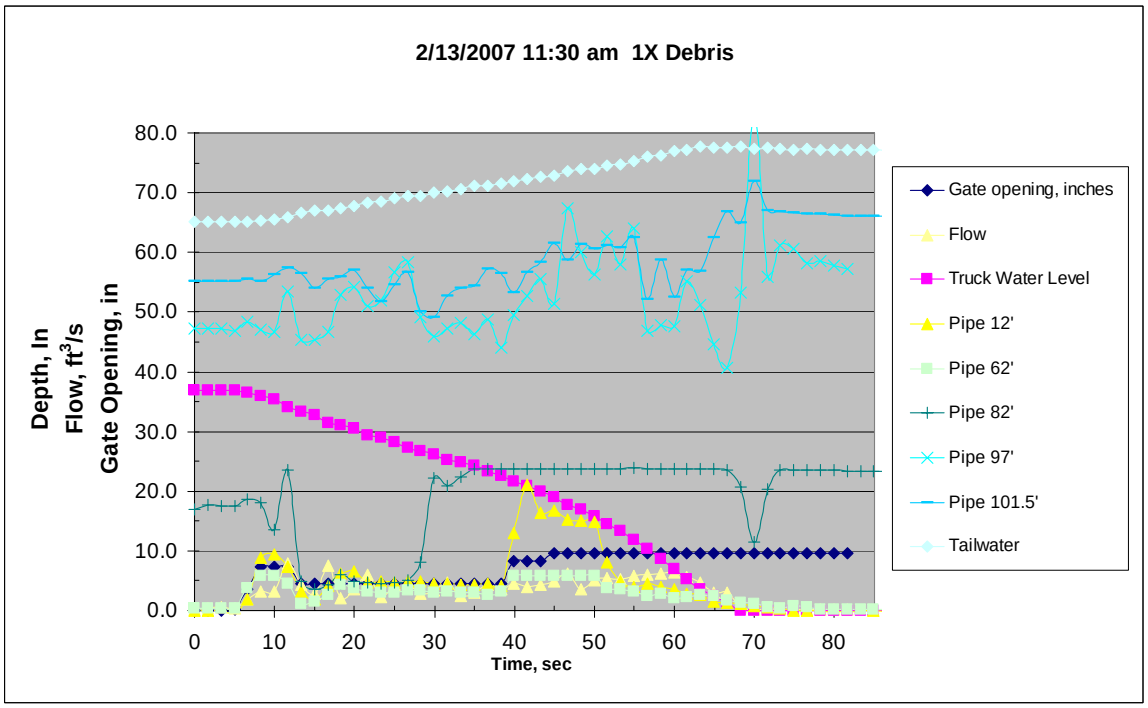

2/06/2007 2:30 am 0 Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

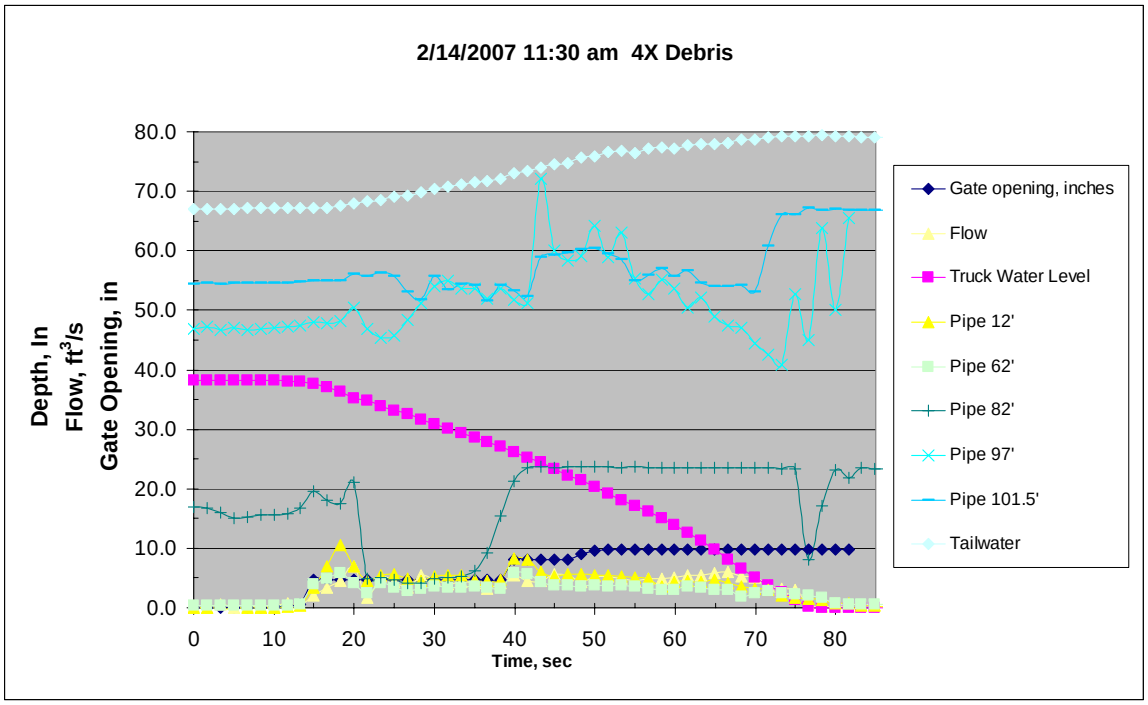

2/07/2007 9:00 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

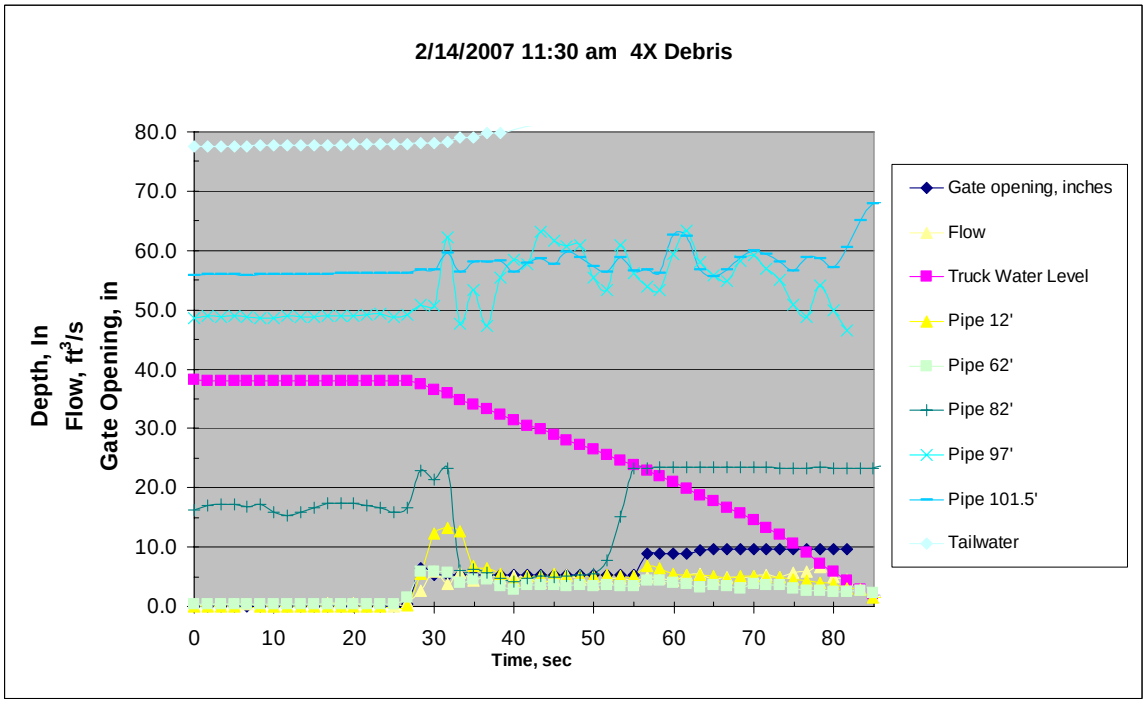

2/07/2007 12:30 pm 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

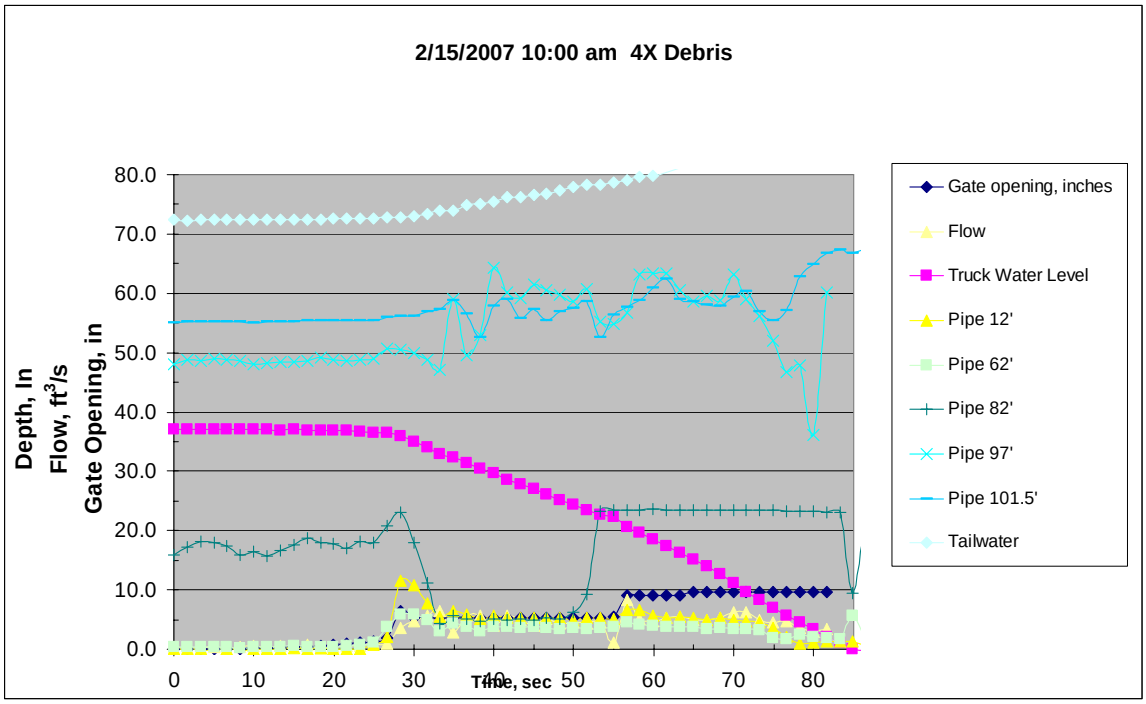

2/07/2007 2:30 pm 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

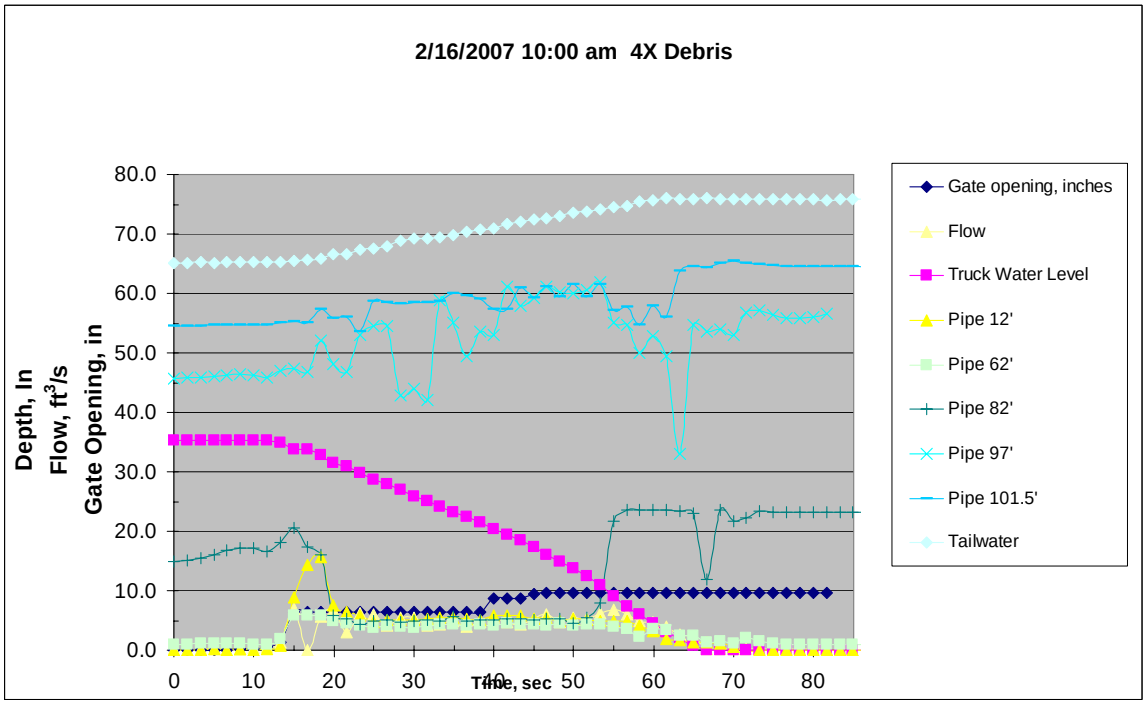

2/13/2007 10:00 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

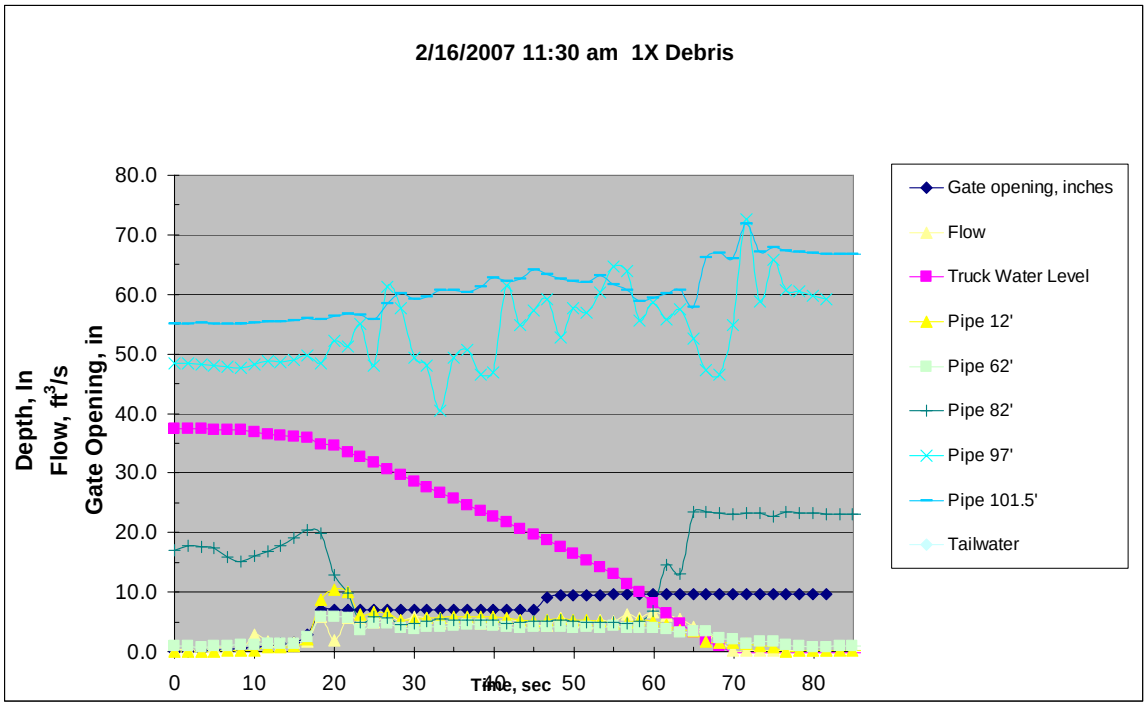

2/13/2007 11:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

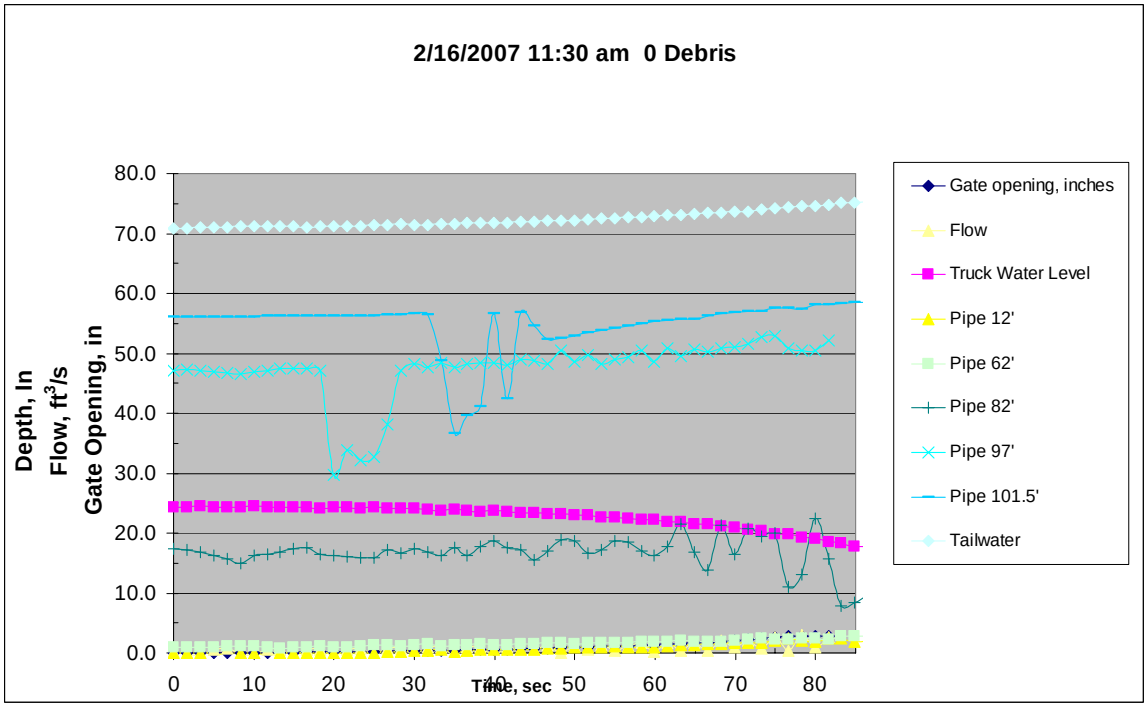

2/14/2007 11:30 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

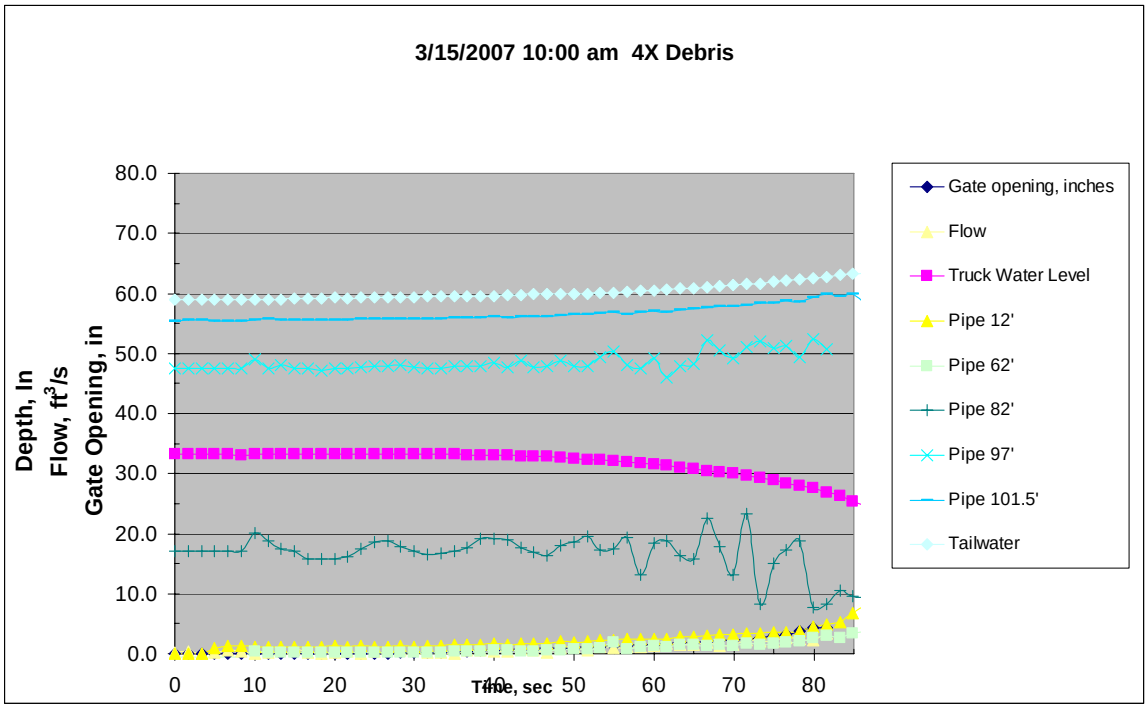

2/14/2007 11:30 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

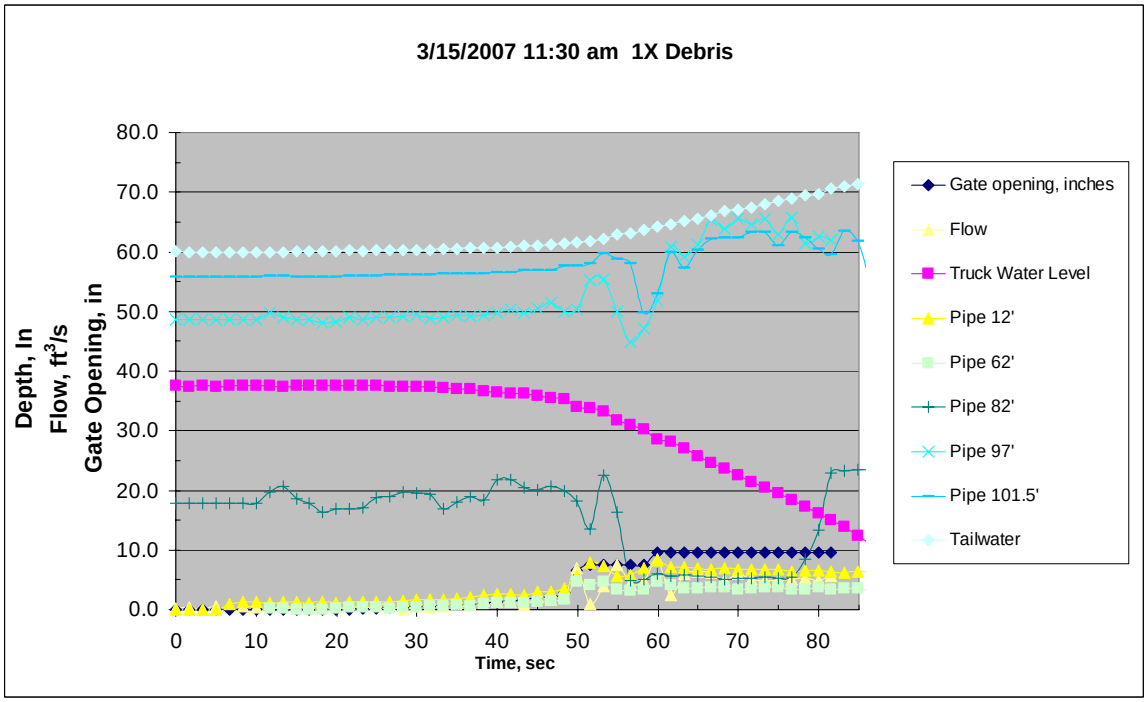

2/15/2007 10:00 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

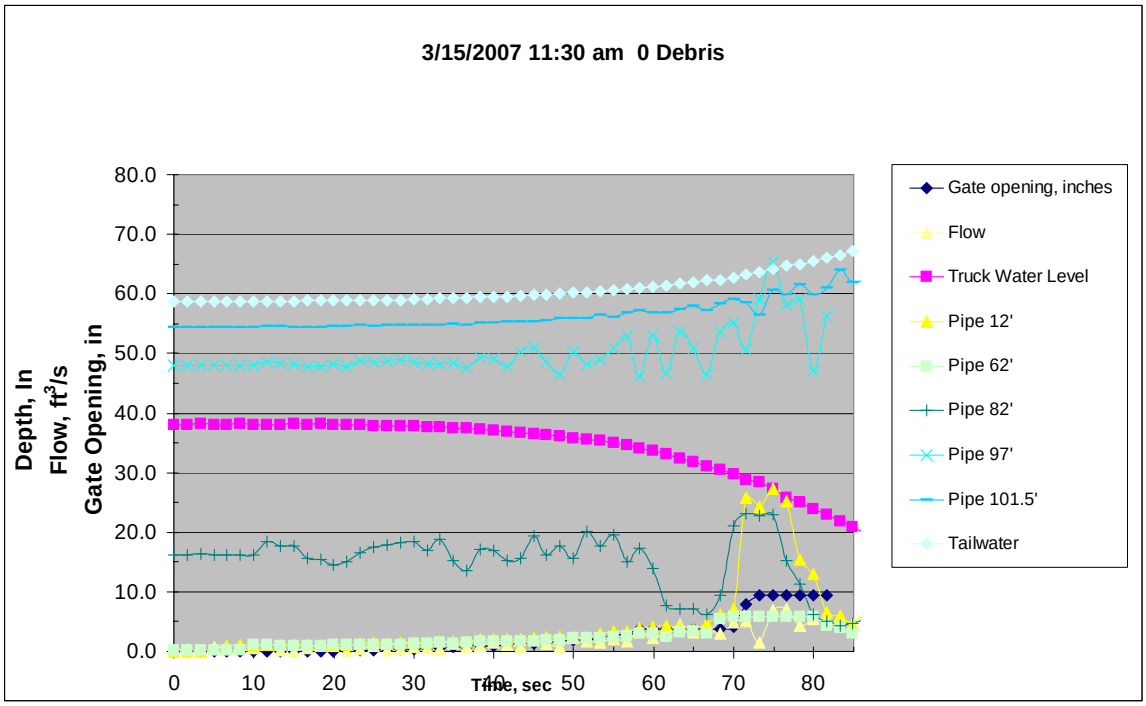

2/16/2007 10:00 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

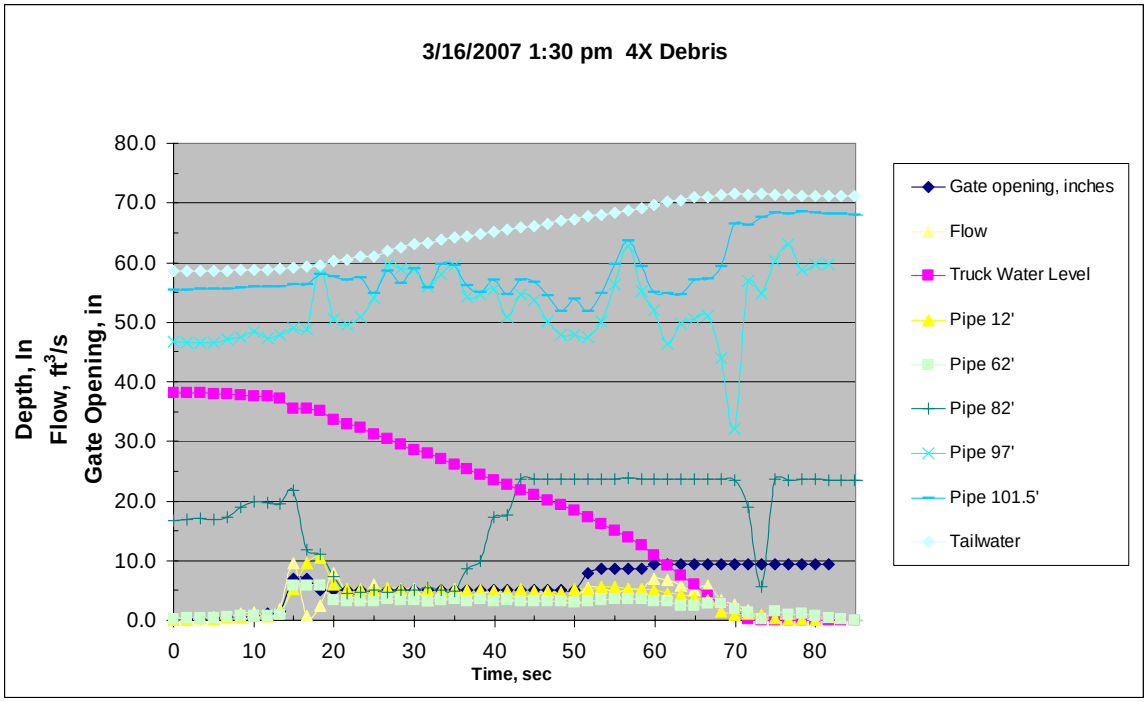

2/16/2007 11:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

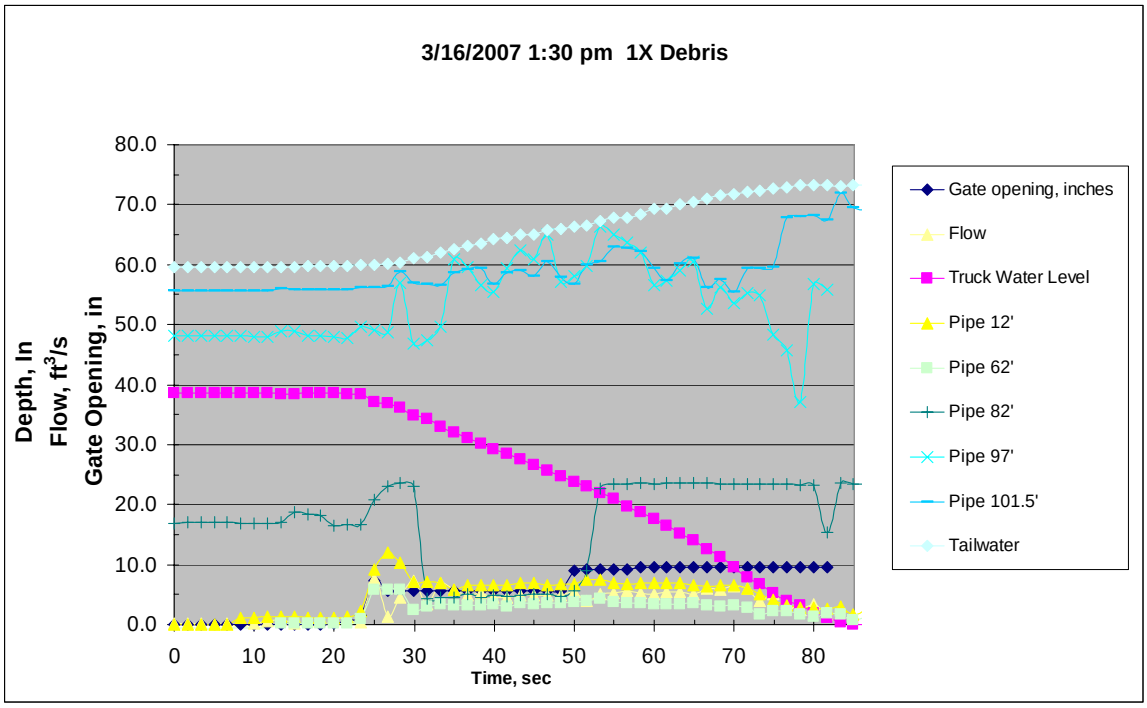

2/16/2007 11:30 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

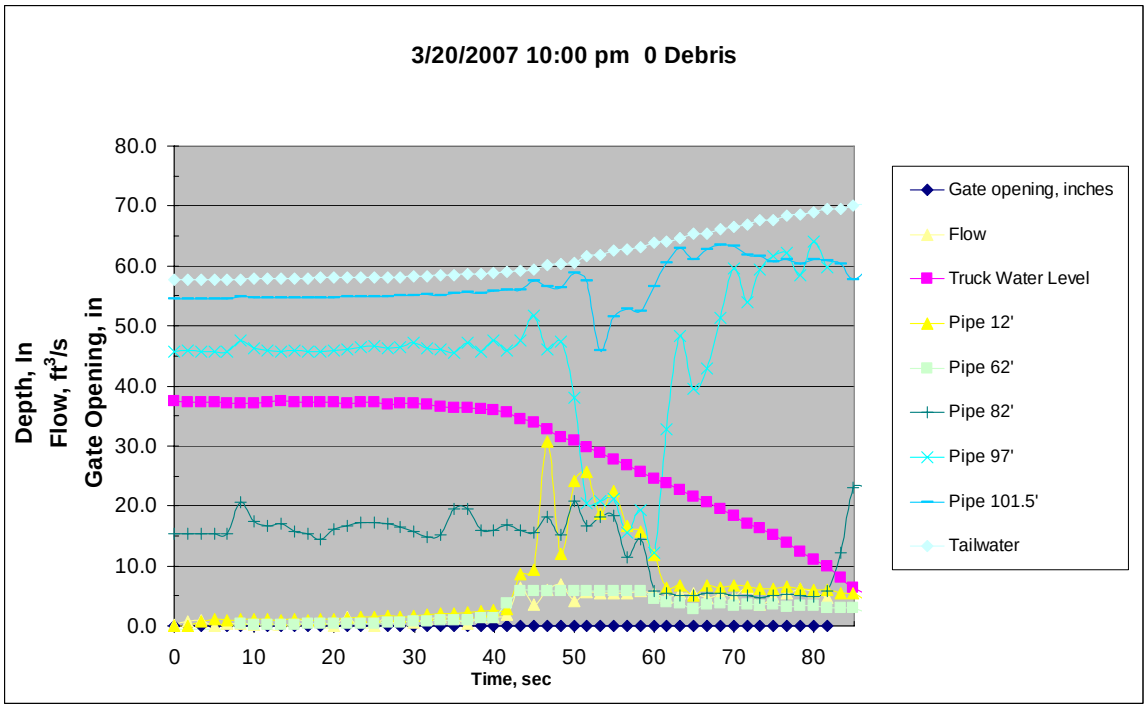

3/15/2007 10:00 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

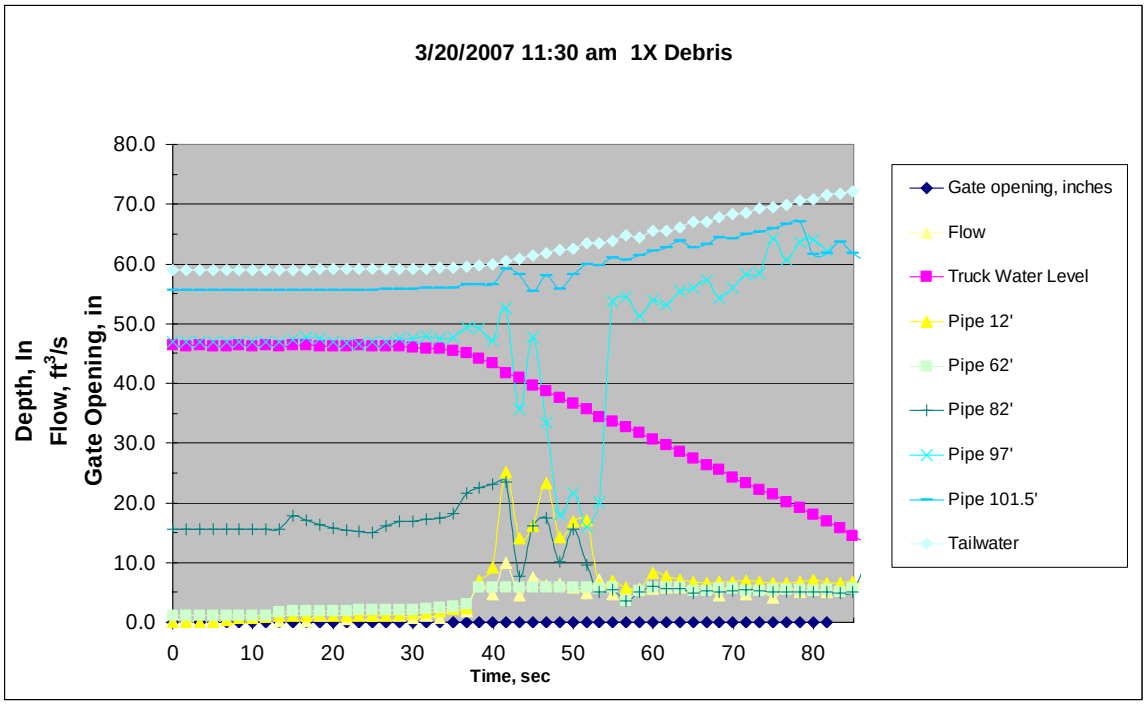

3/15/2007 11:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

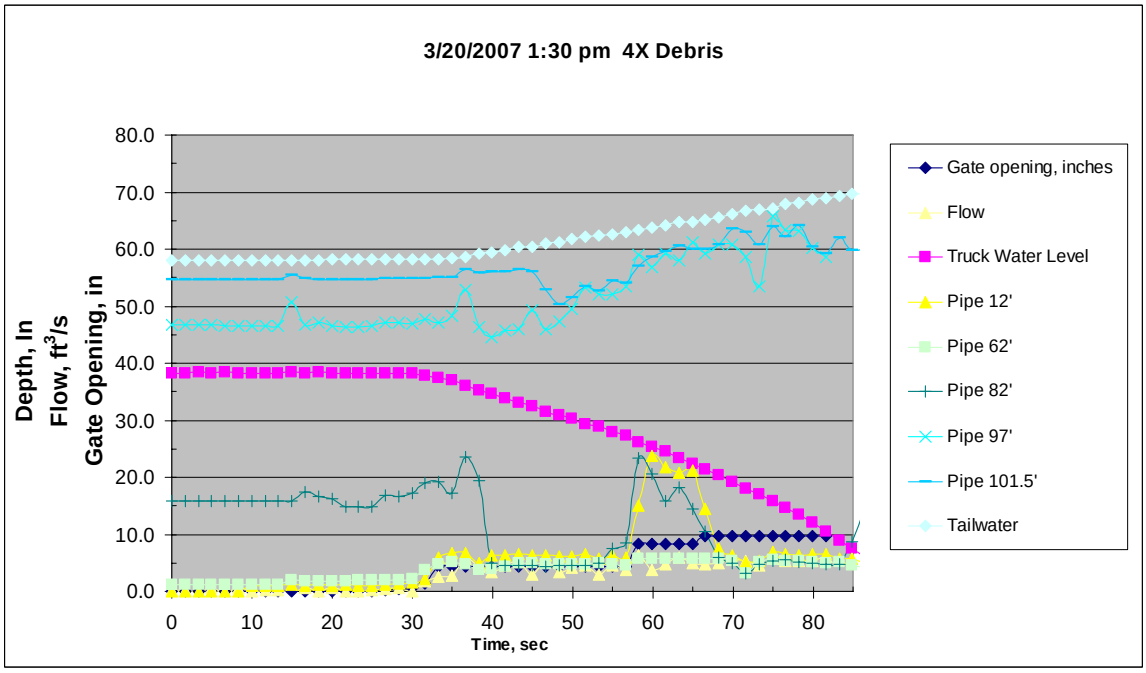

3/15/2007 11:30 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

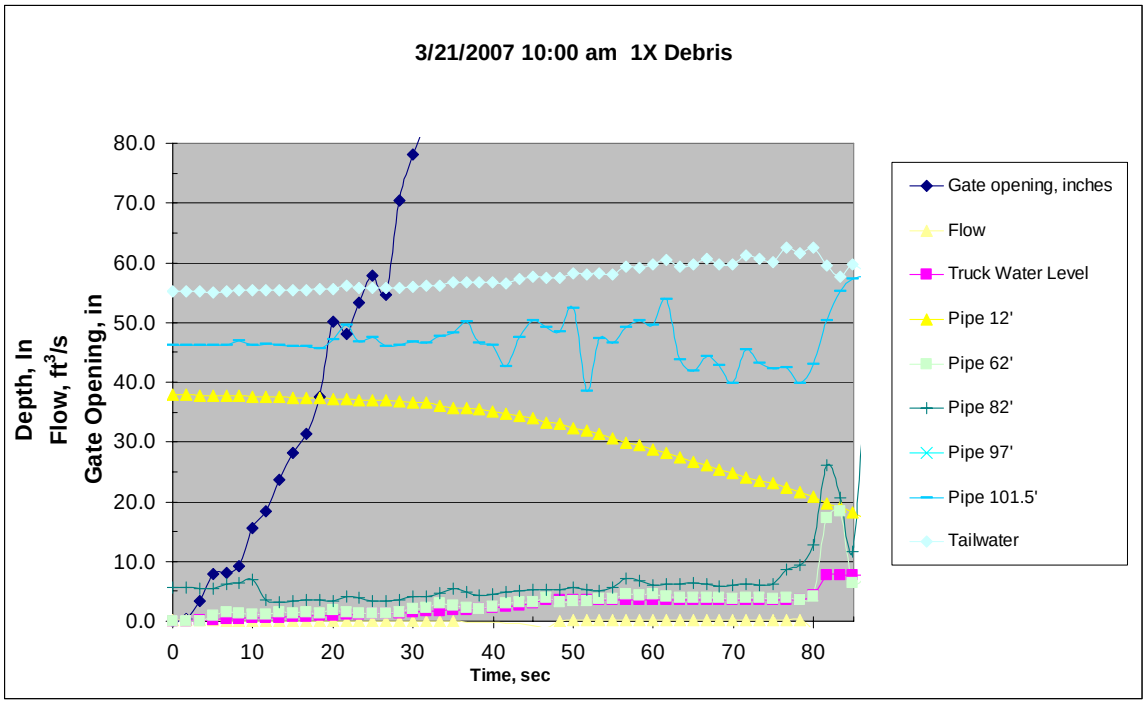

3/16/2007 1:30 pm 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

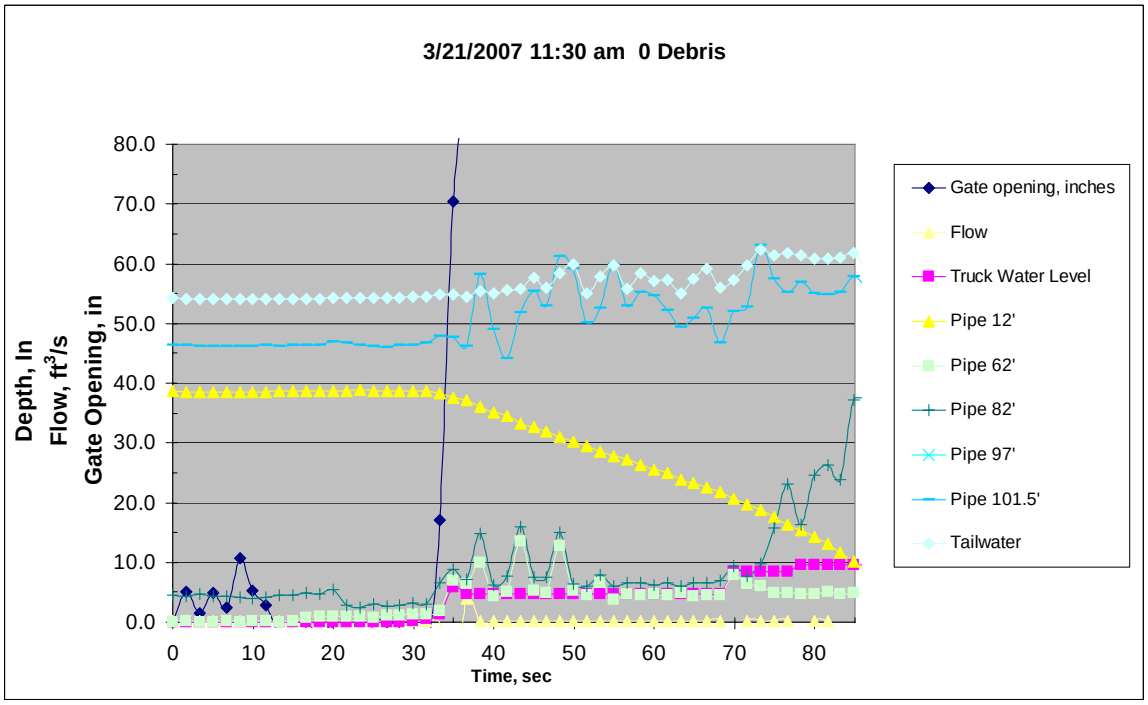

3/16/2007 1:30 pm 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

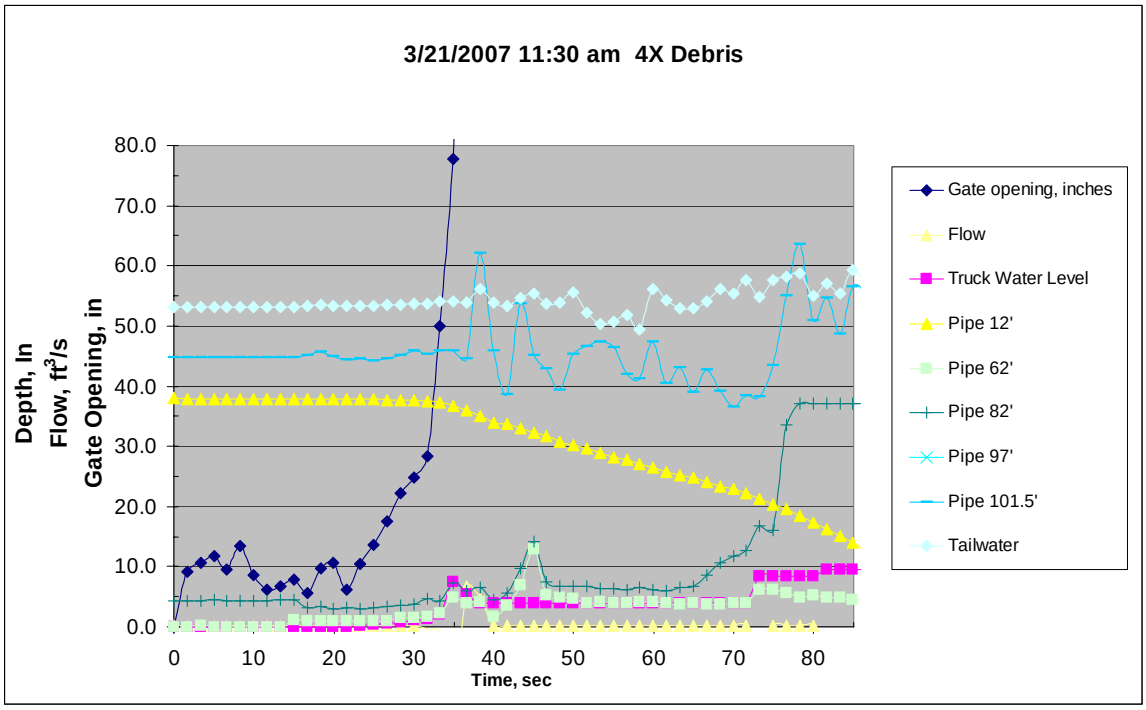

3/20/2007 10:00 pm 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

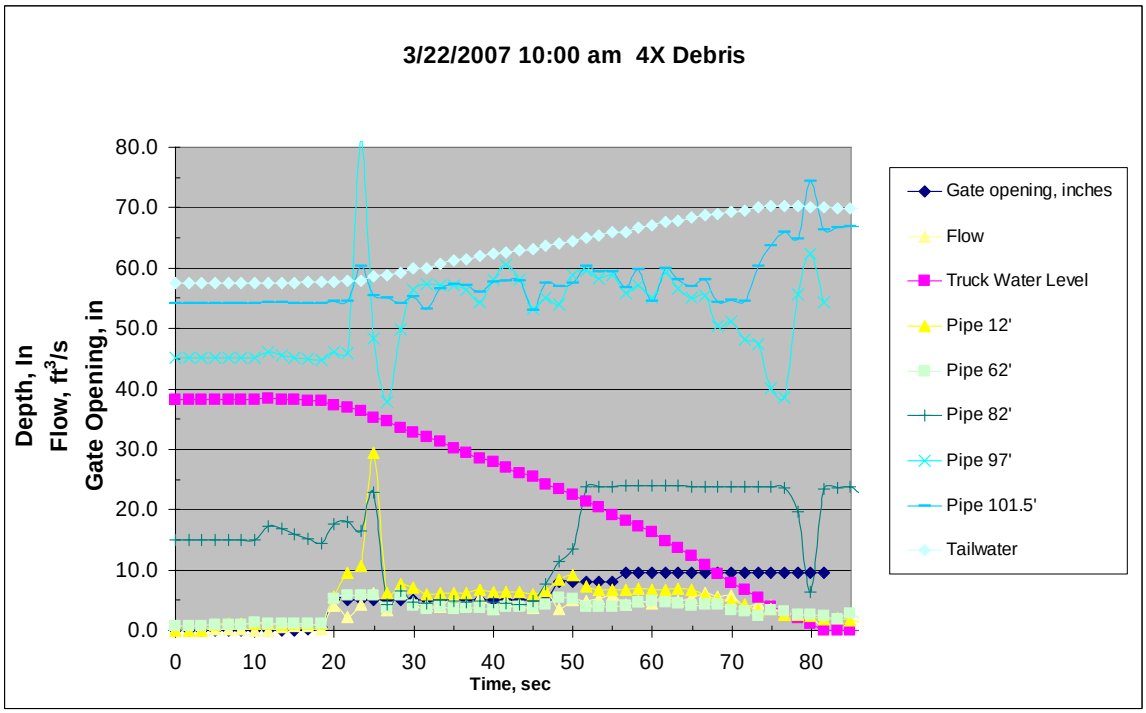

3/20/2007 11:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

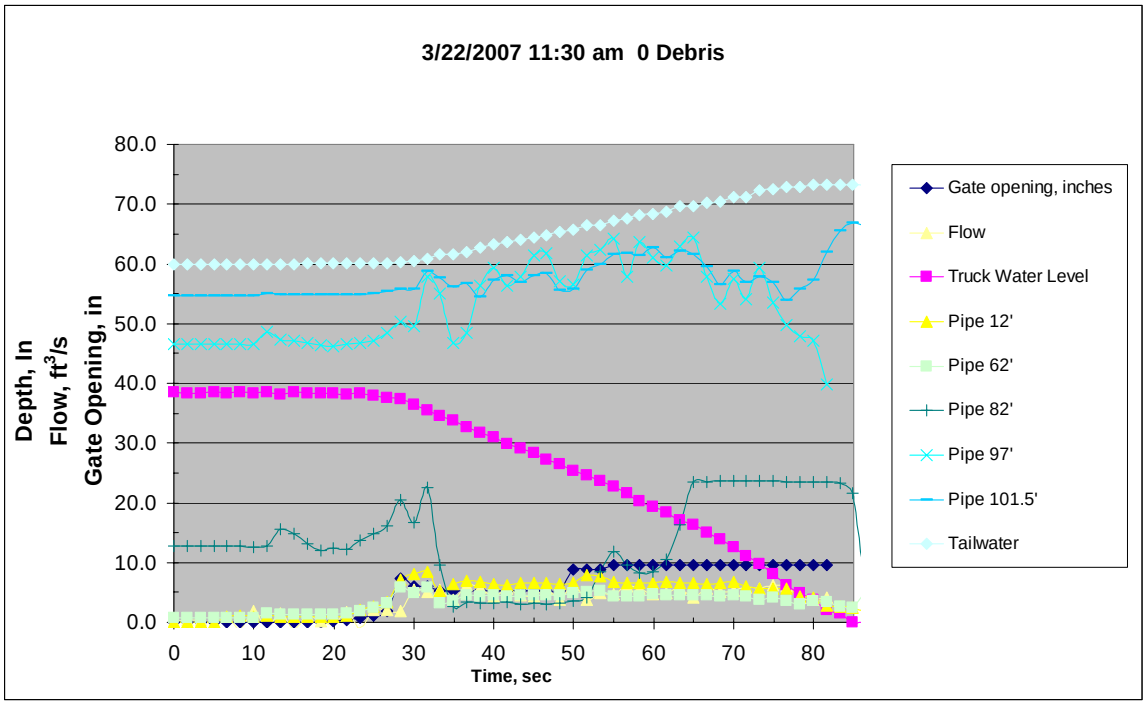

3/20/2007 1:30 pm 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

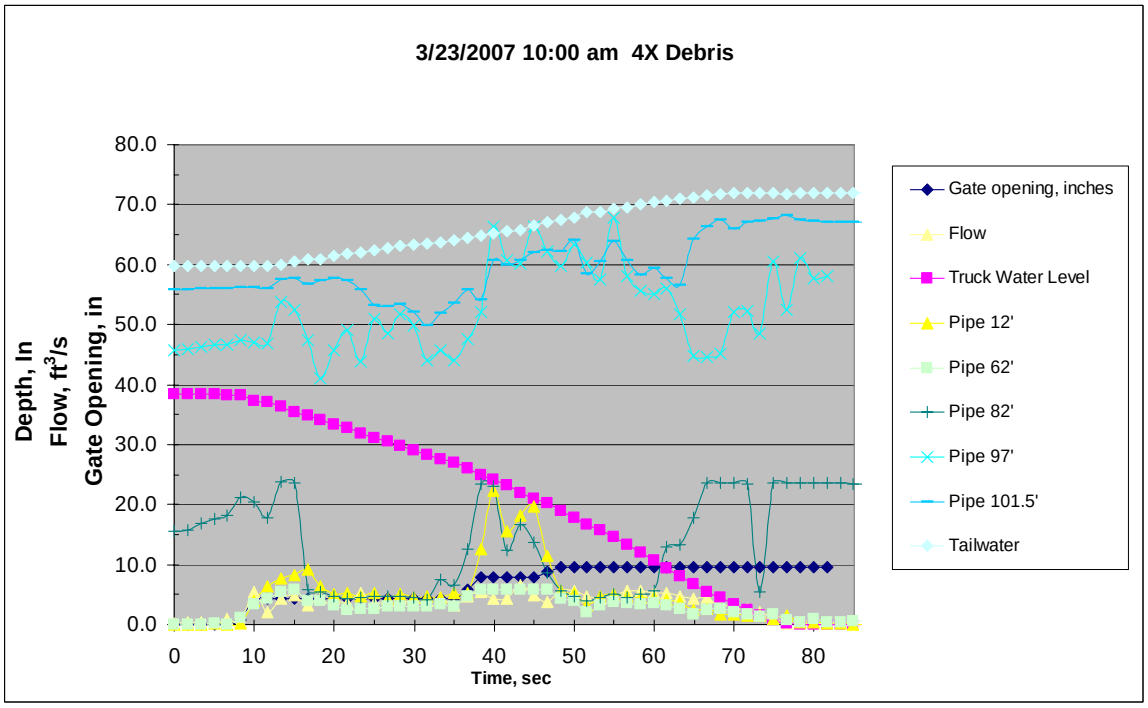

3/21/2007 10:00 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

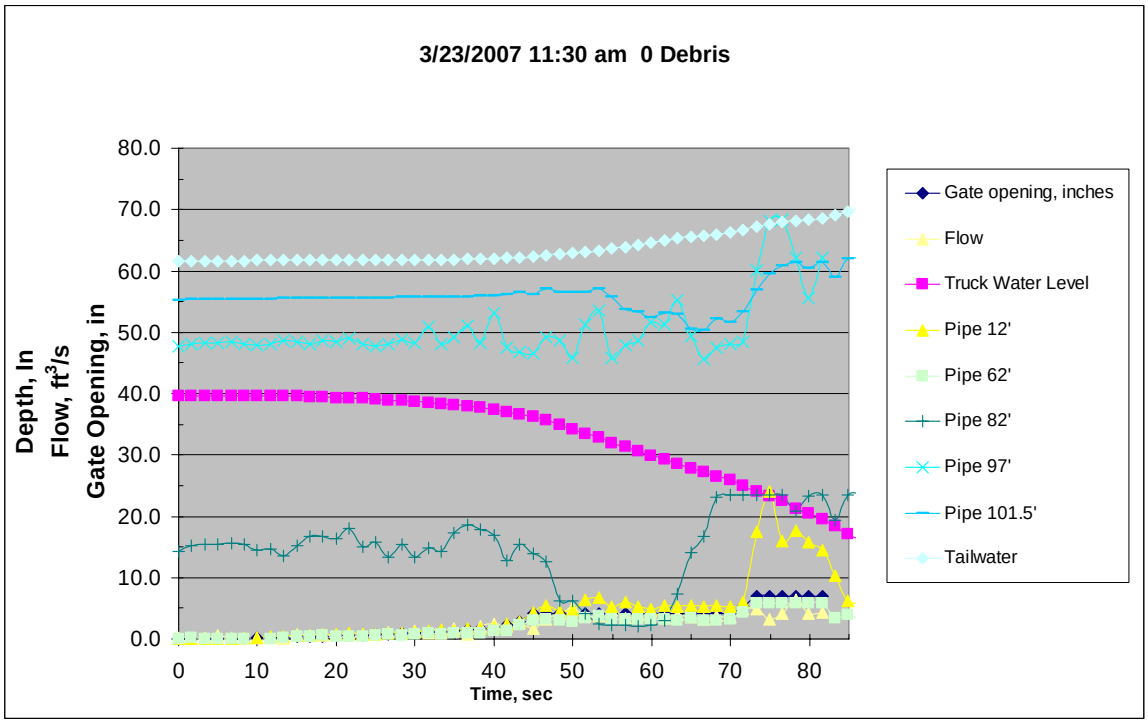

3/21/2007 11:30 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

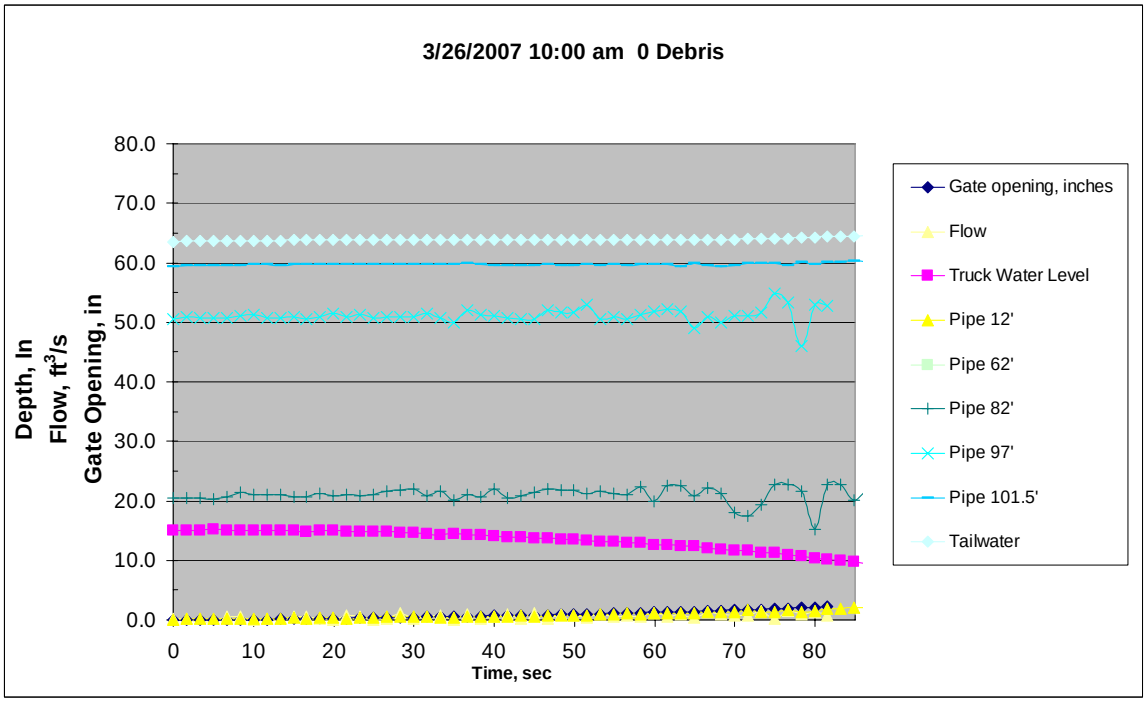

3/21/2007 11:30 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

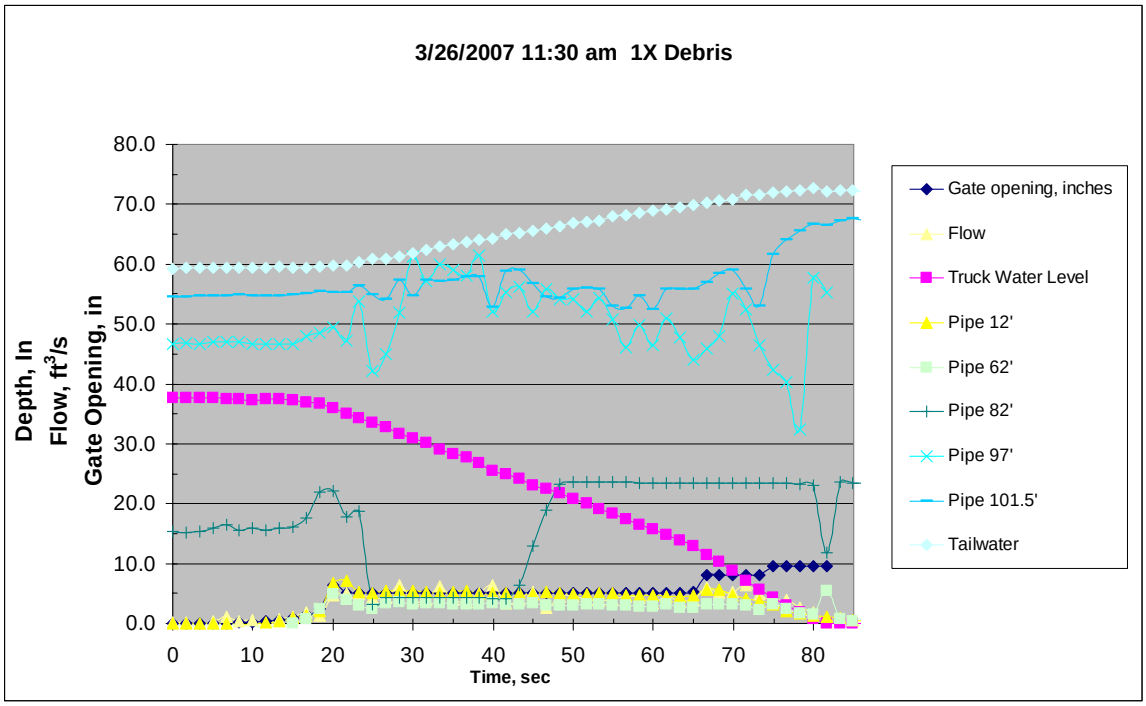

3/22/2007 10:00 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

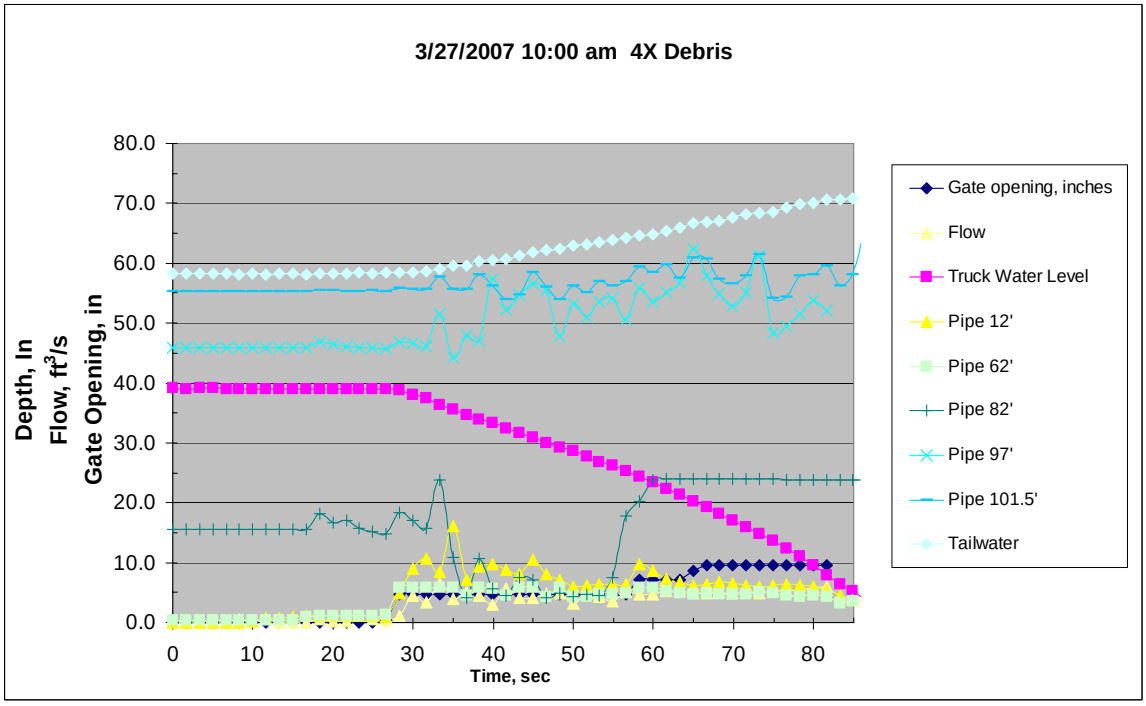

3/22/2007 11:30 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

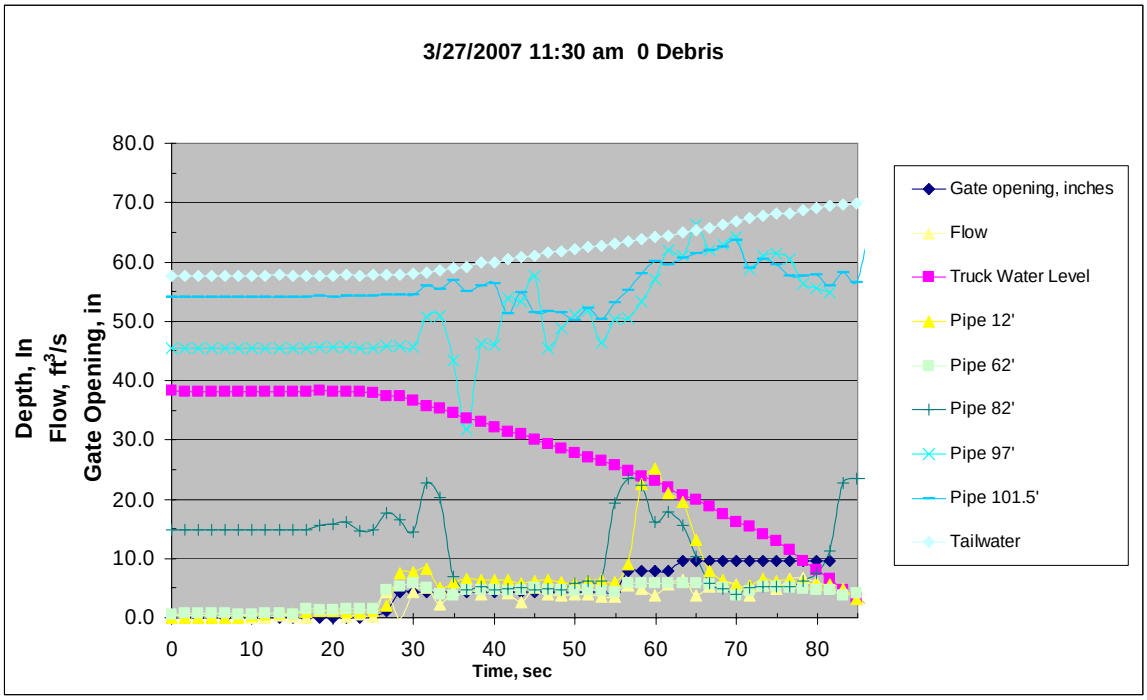

3/23/2007 10:00 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

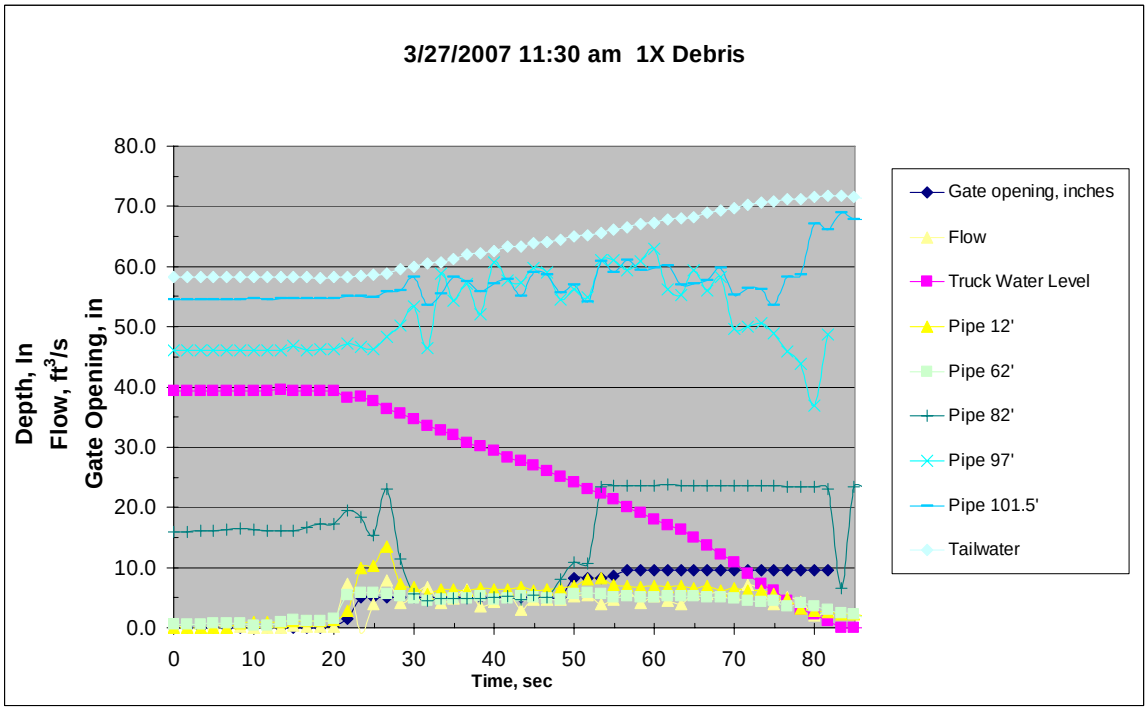

3/23/2007 11:30 am 0 Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

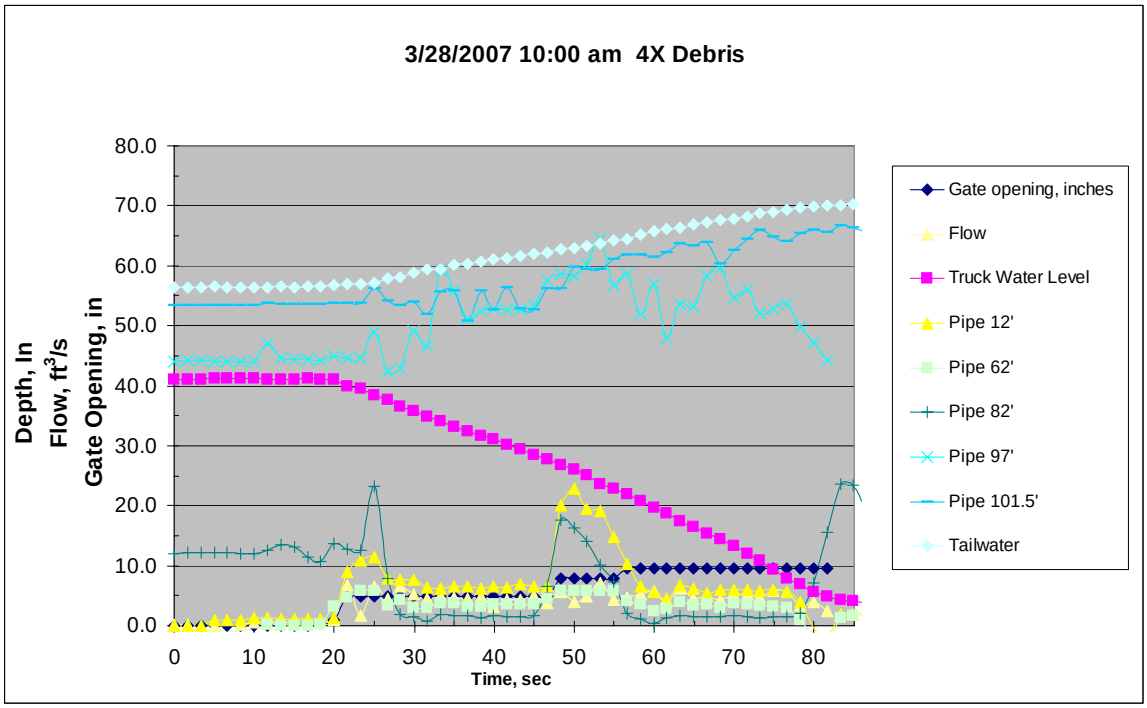

3/26/2007 10:00 am 0 Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

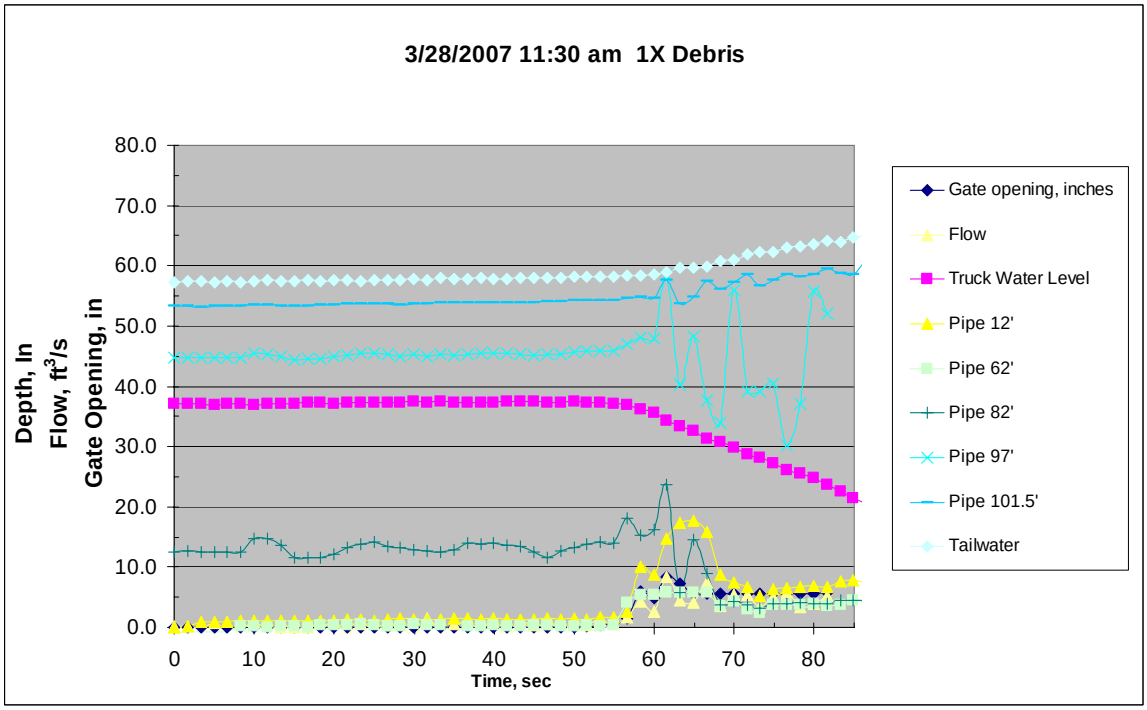

3/26/2007 11:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

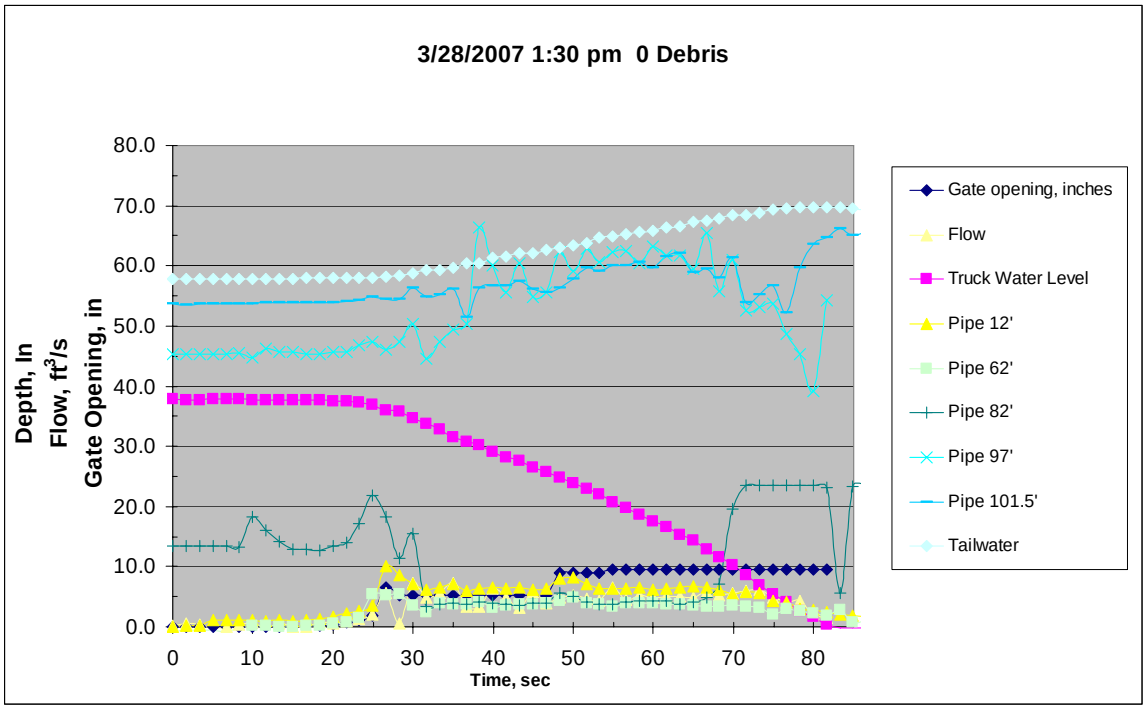

3/27/2007 10:00 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

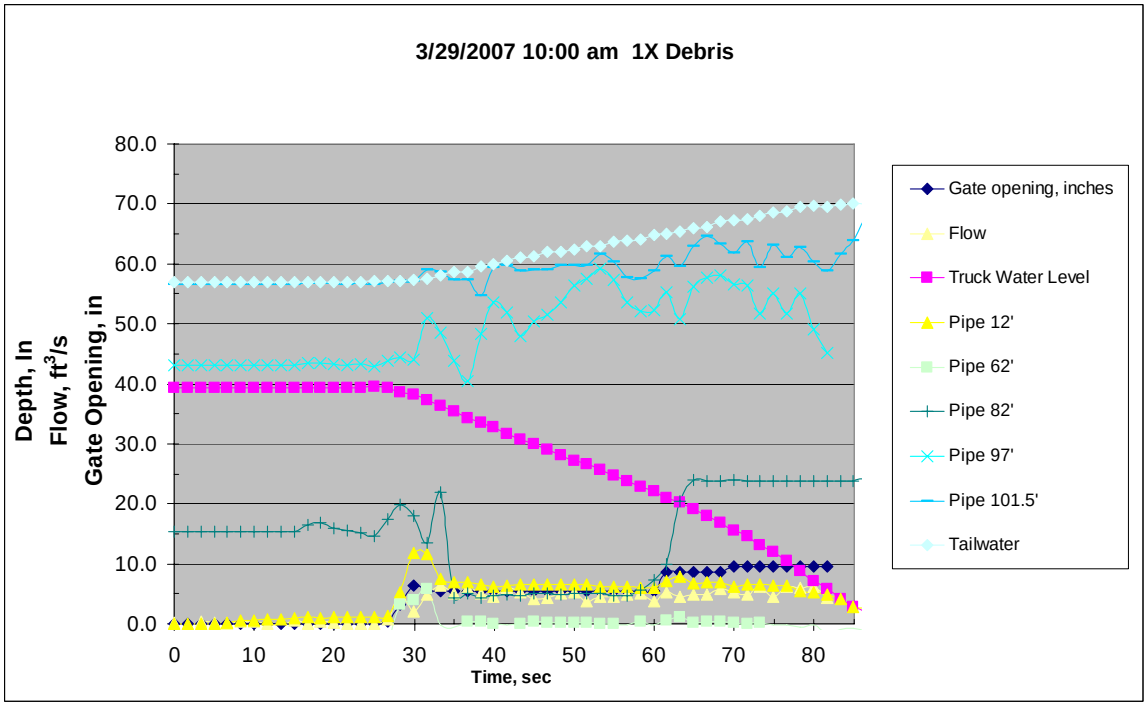

3/27/2007 11:30 am 0 Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

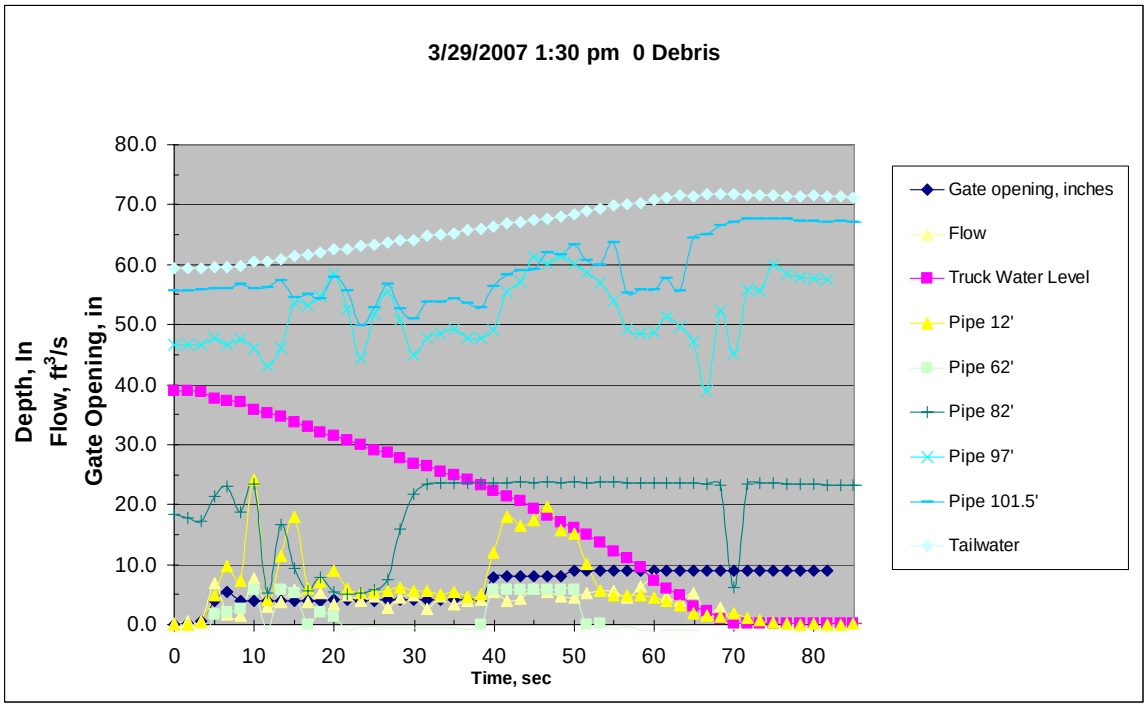

3/27/2007 11:30 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

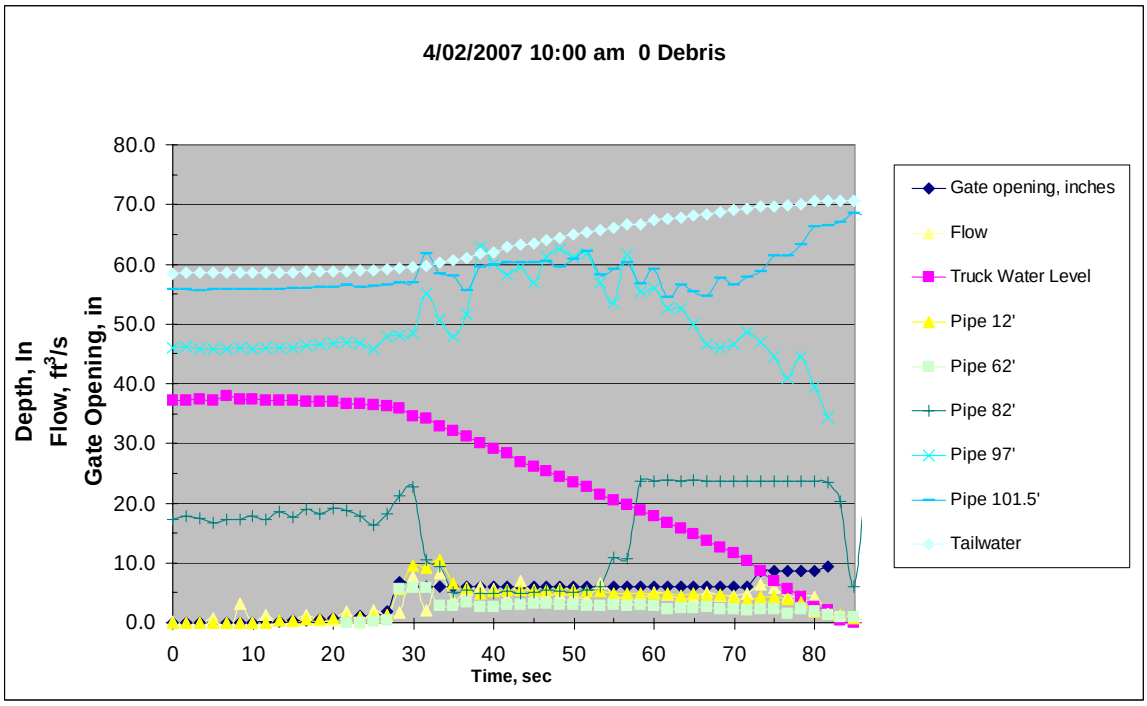

3/28/2007 10:00 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

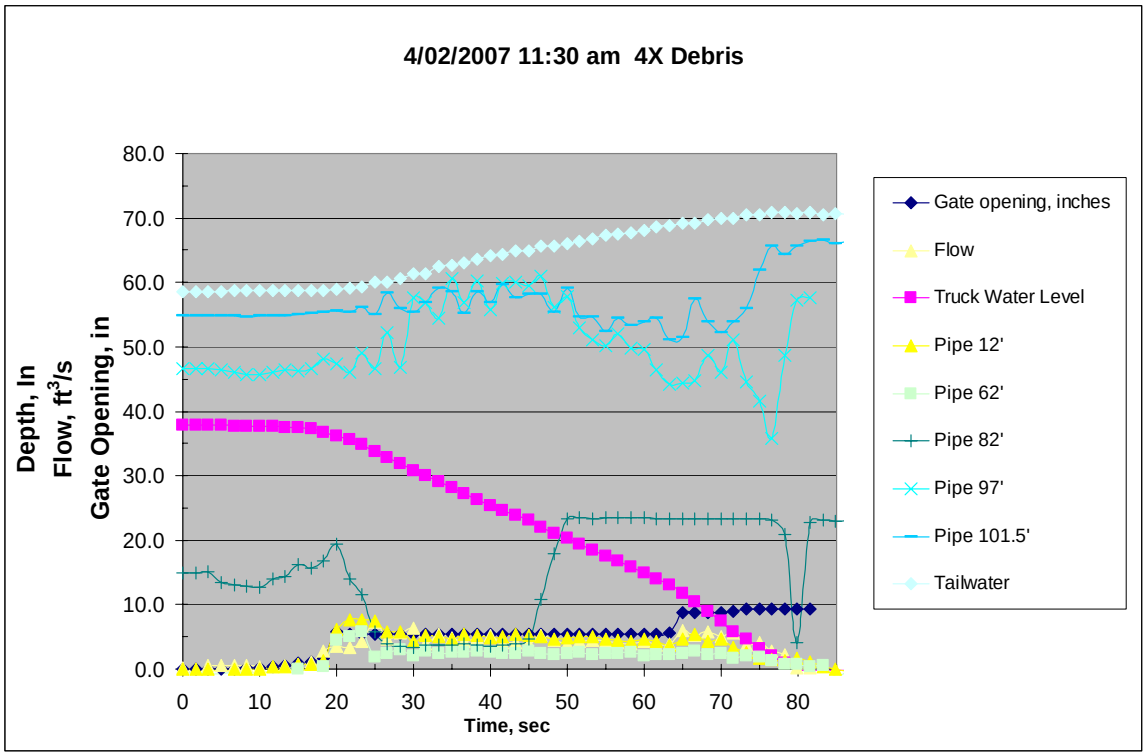

3/28/2007 11:30 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

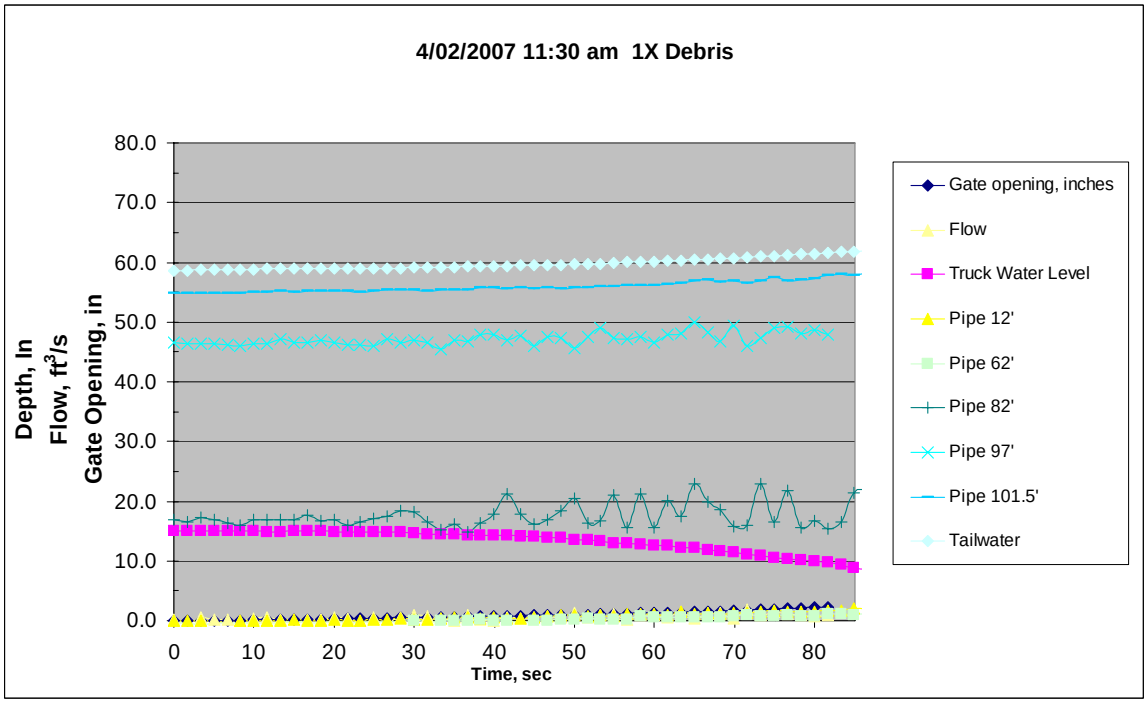

3/28/2007 1:30 pm 0 Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

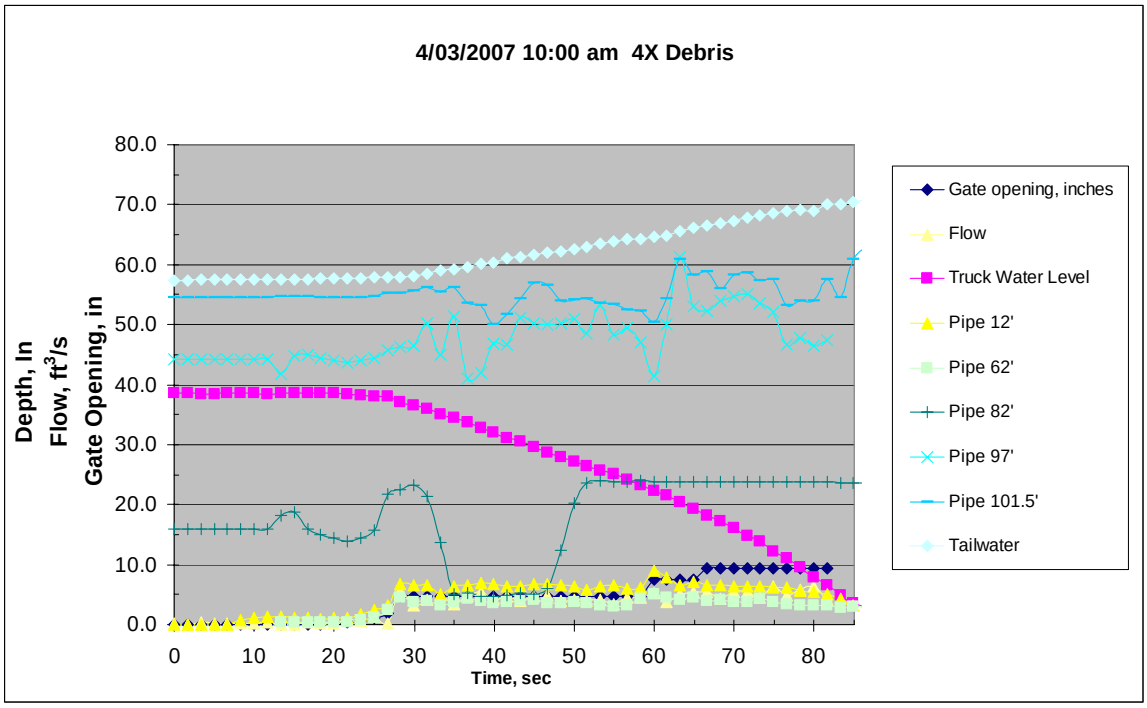

3/29/2007 10:00 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

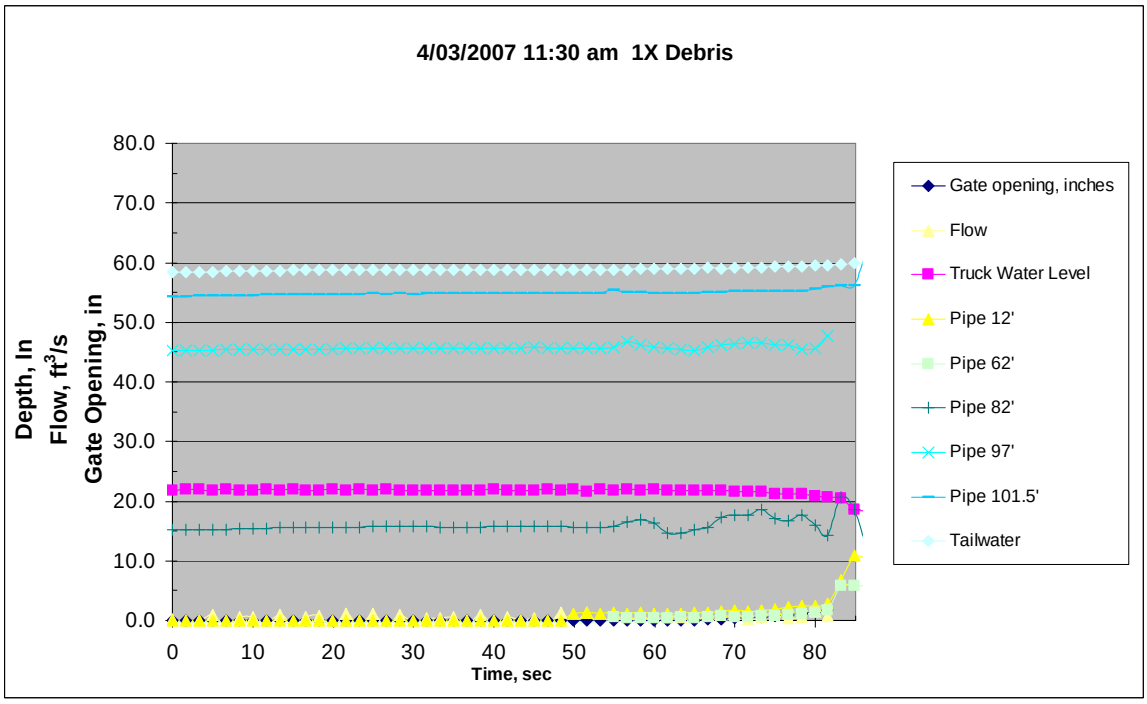

3/29/2007 1:30 pm 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

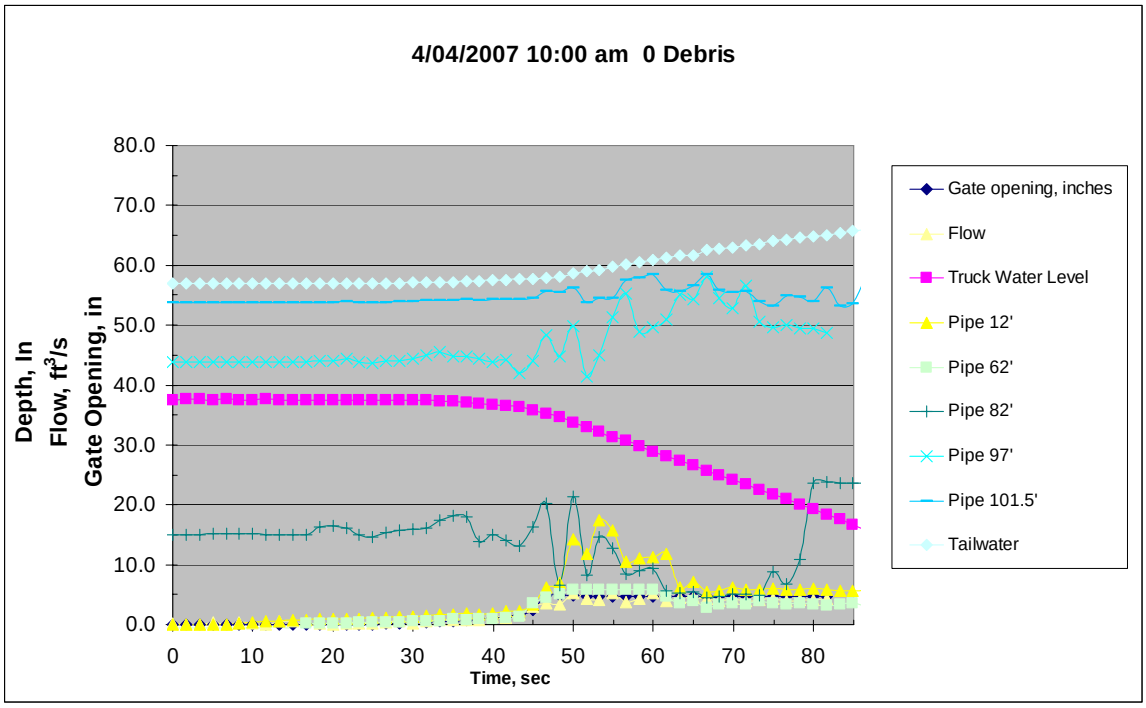

4/02/2007 10:00 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

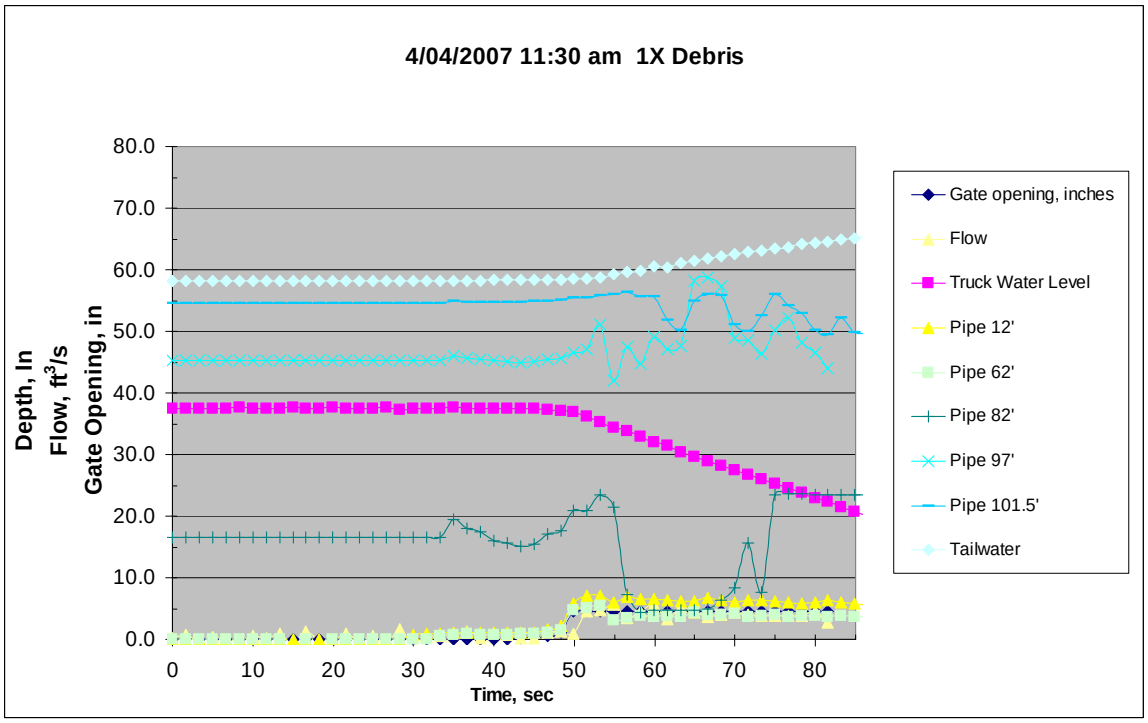

4/02/2007 11:30 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

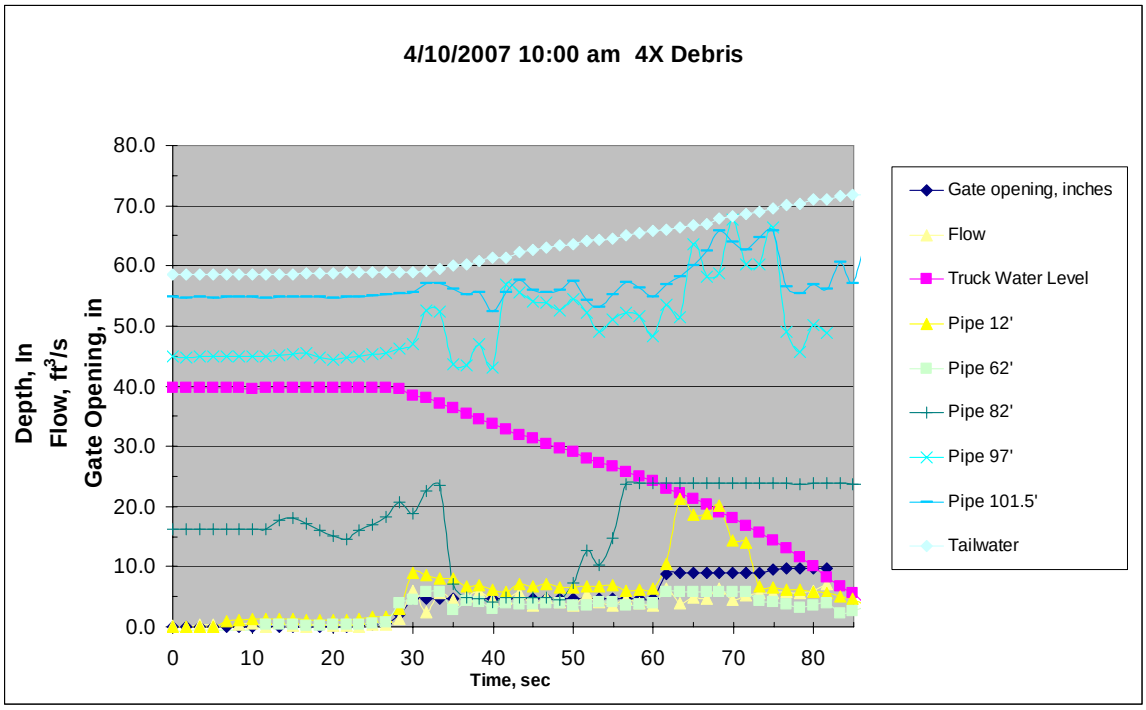

4/02/2007 11:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

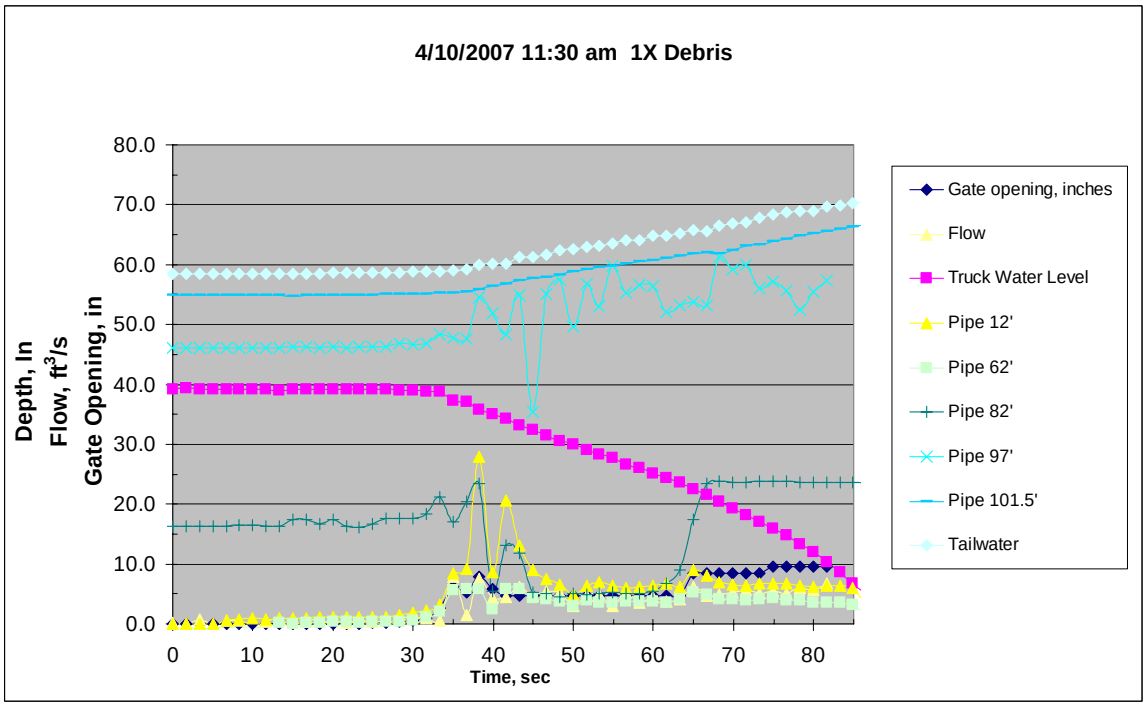

4/03/2007 10:00 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

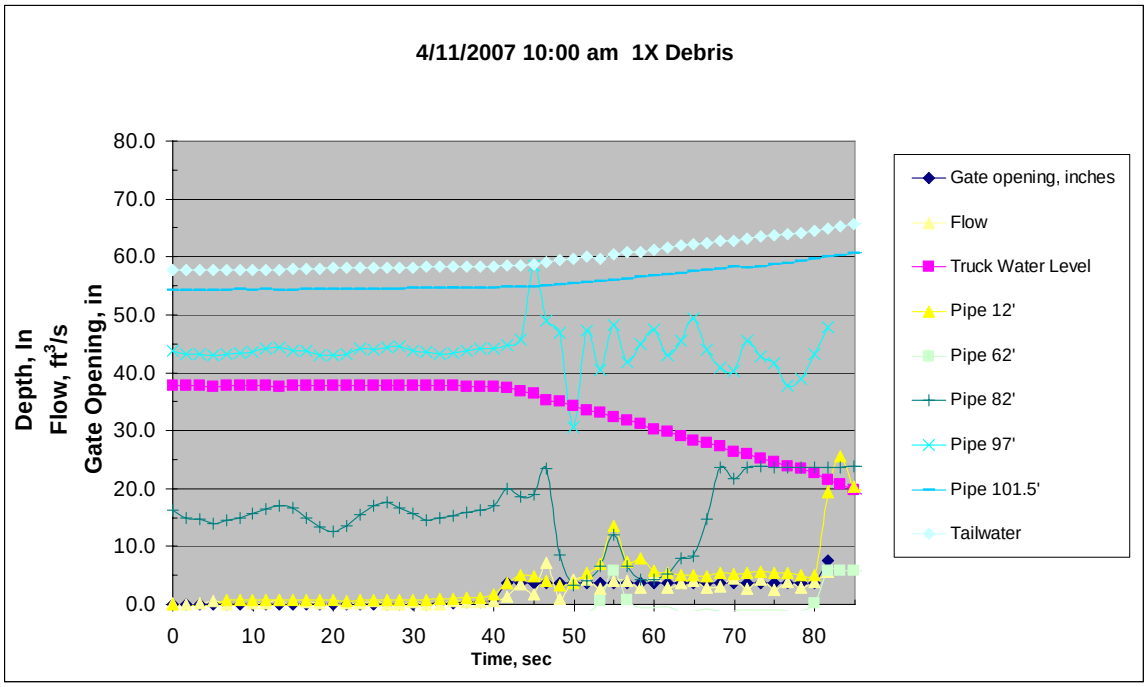

4/03/2007 11:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

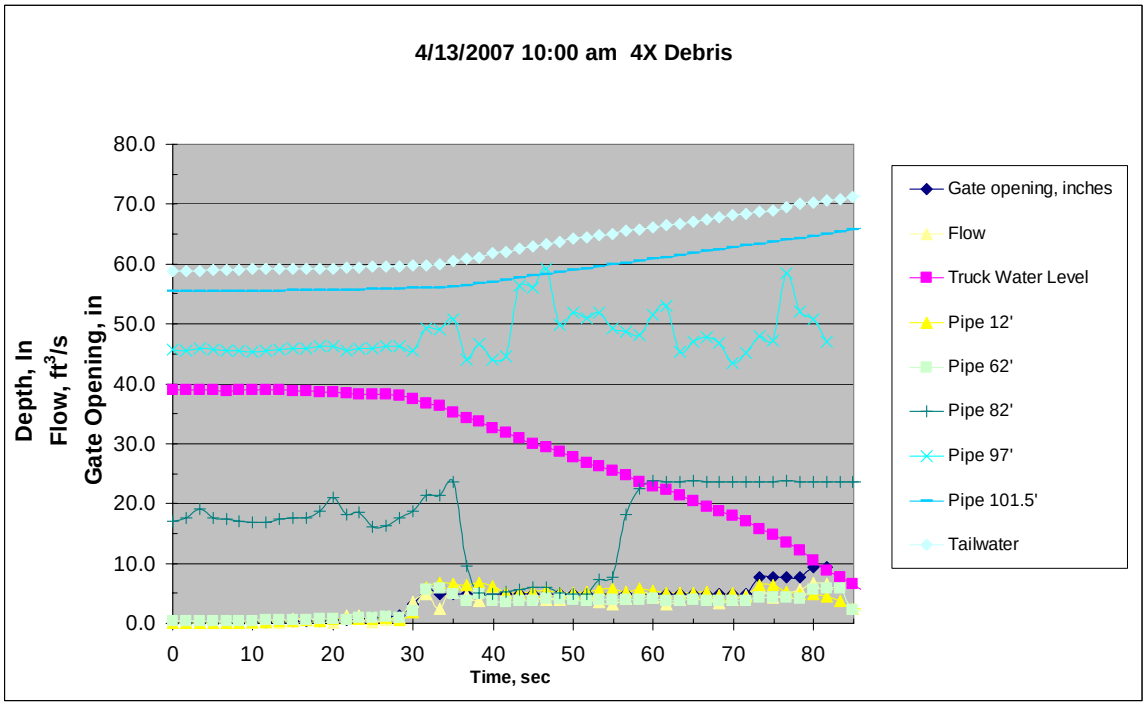

4/04/2007 10:00 am 0 Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

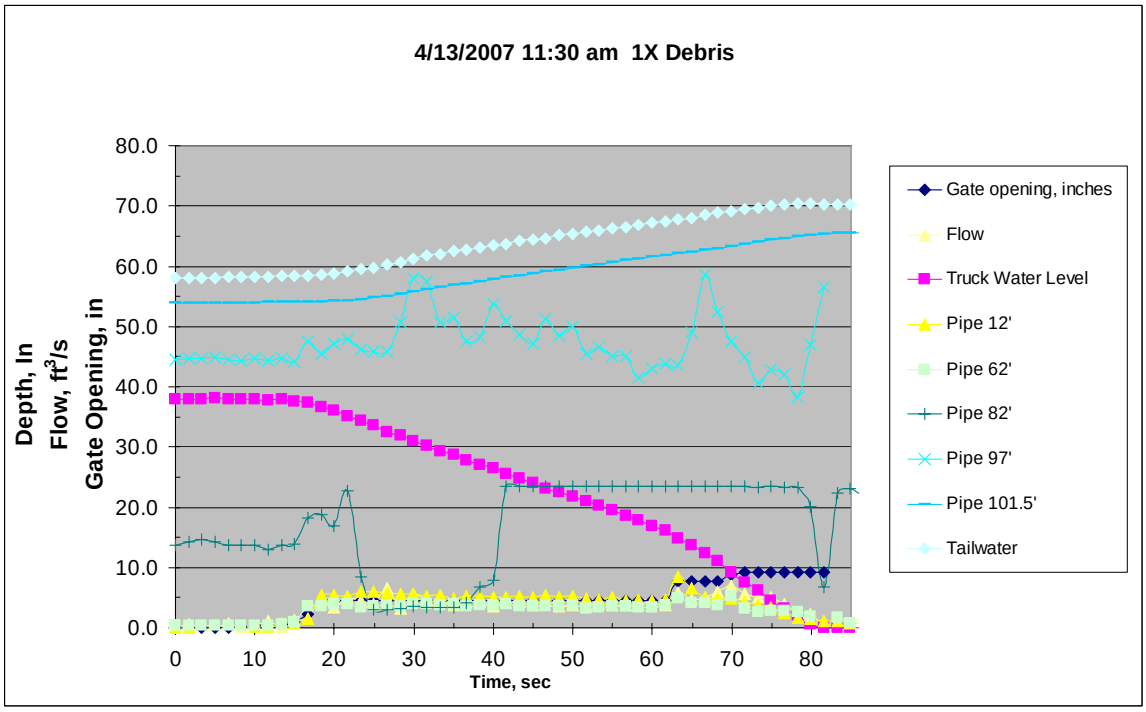

4/04/2007 11:30 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

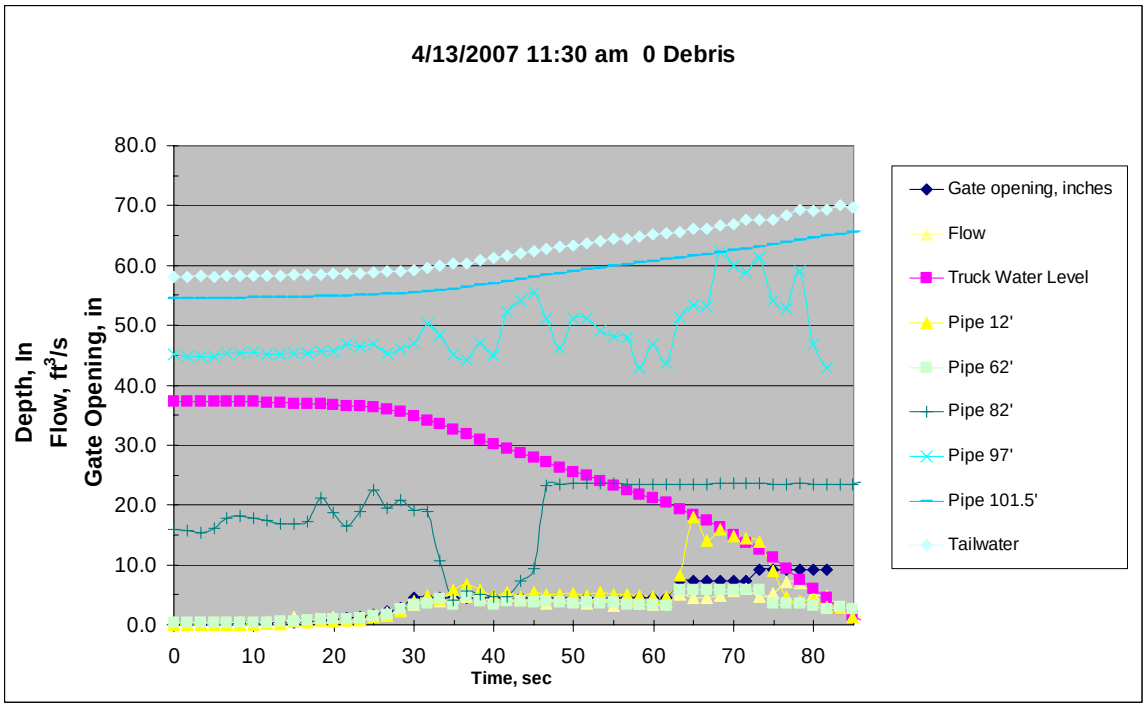

4/10/2007 10:00 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

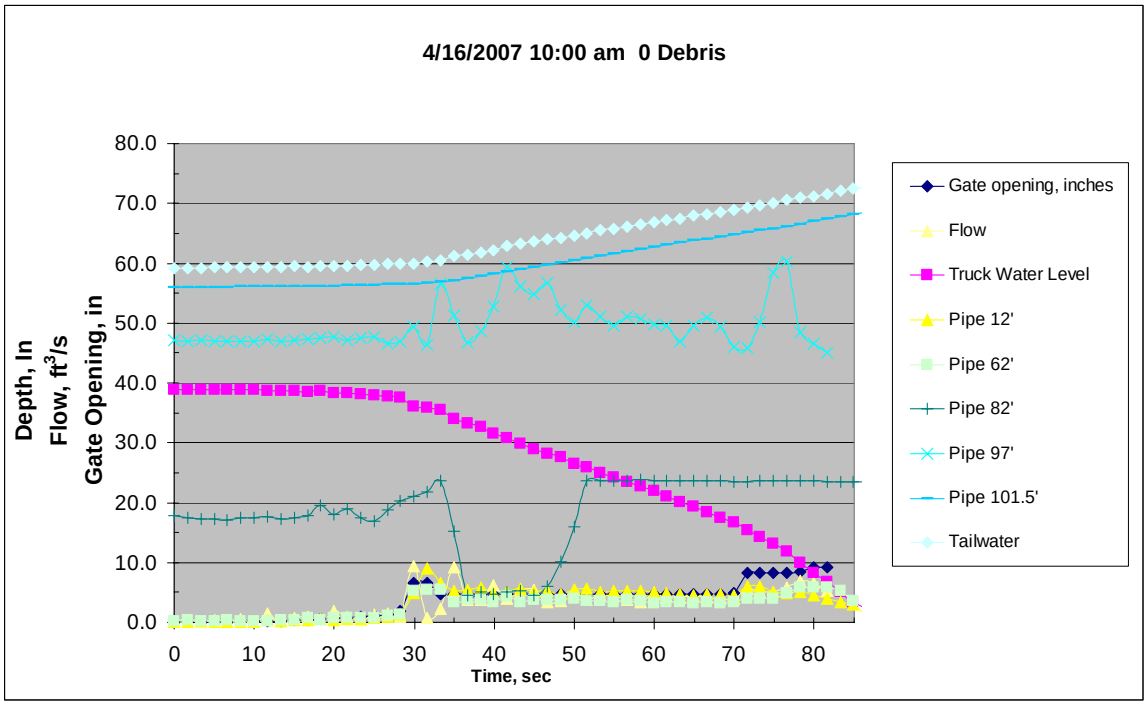

4/10/2007 11:30 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

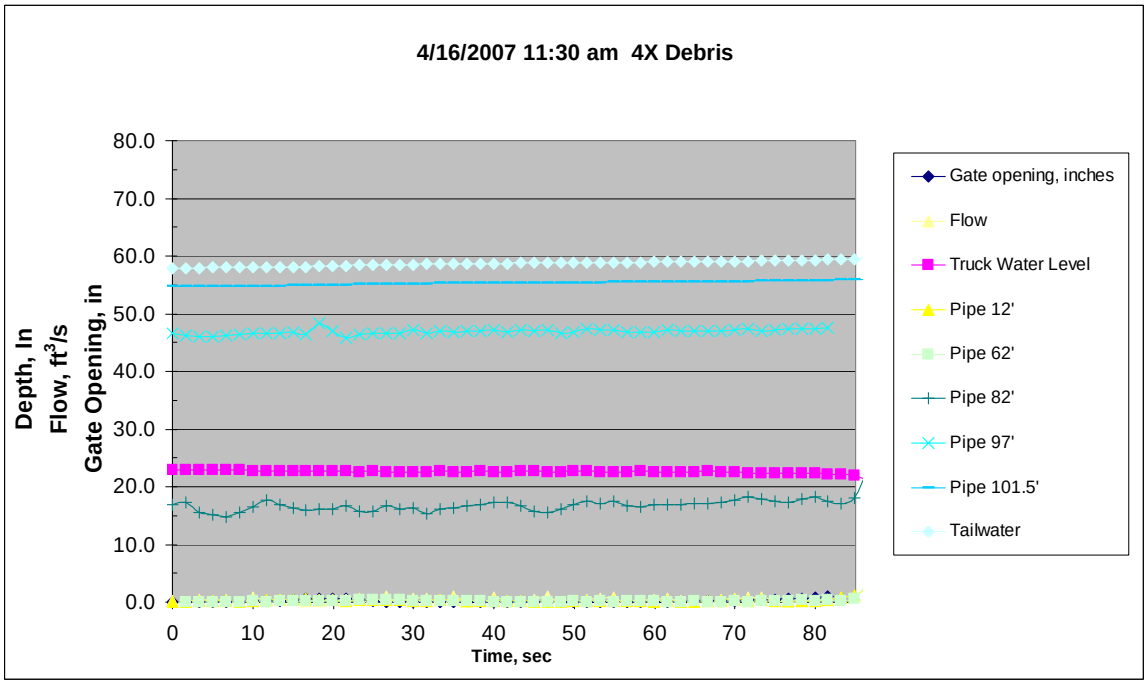

4/11/2007 10:00 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

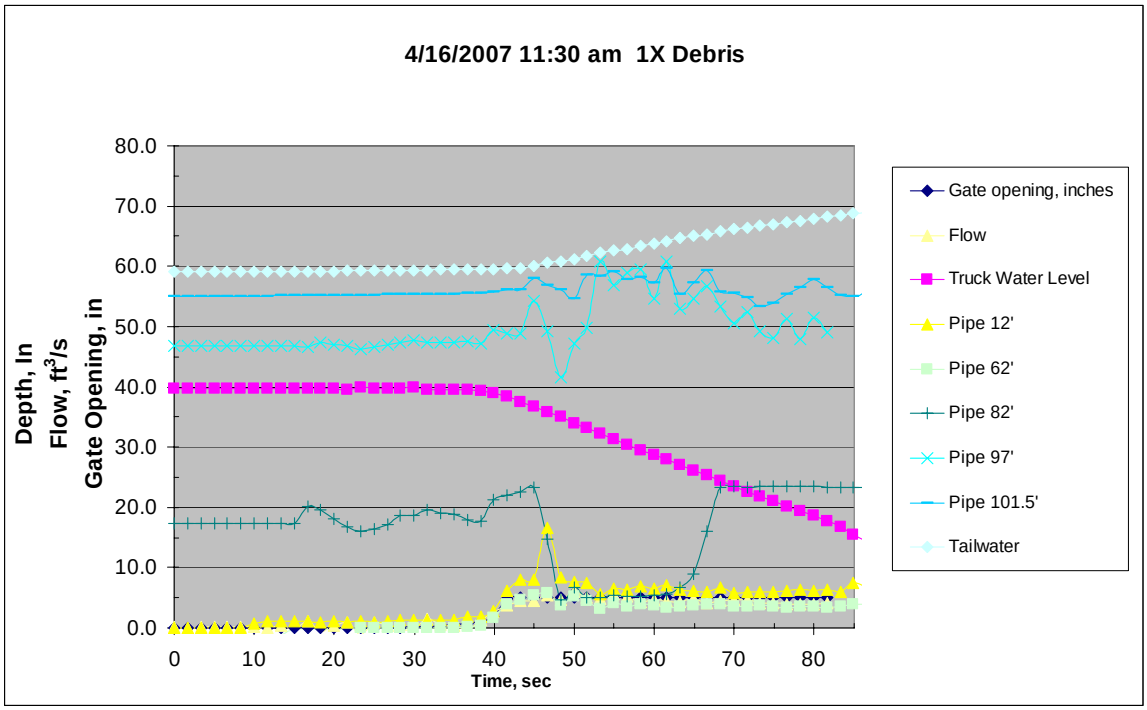

4/13/2007 10:00 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

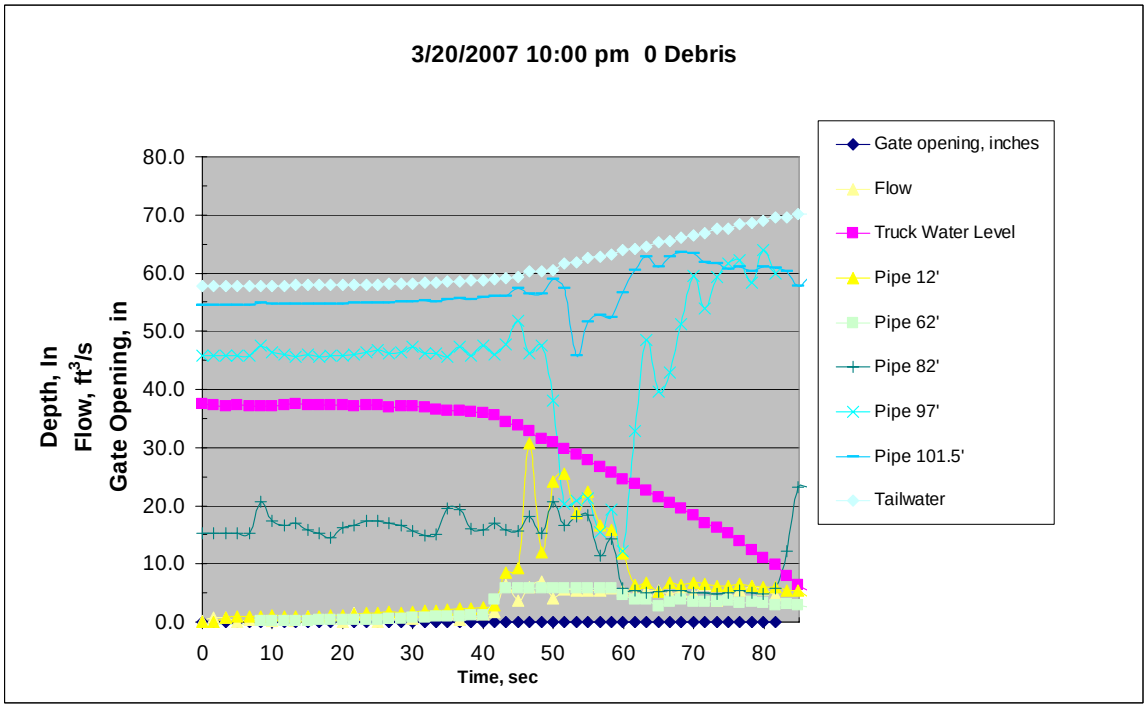

4/13/2007 11:30 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

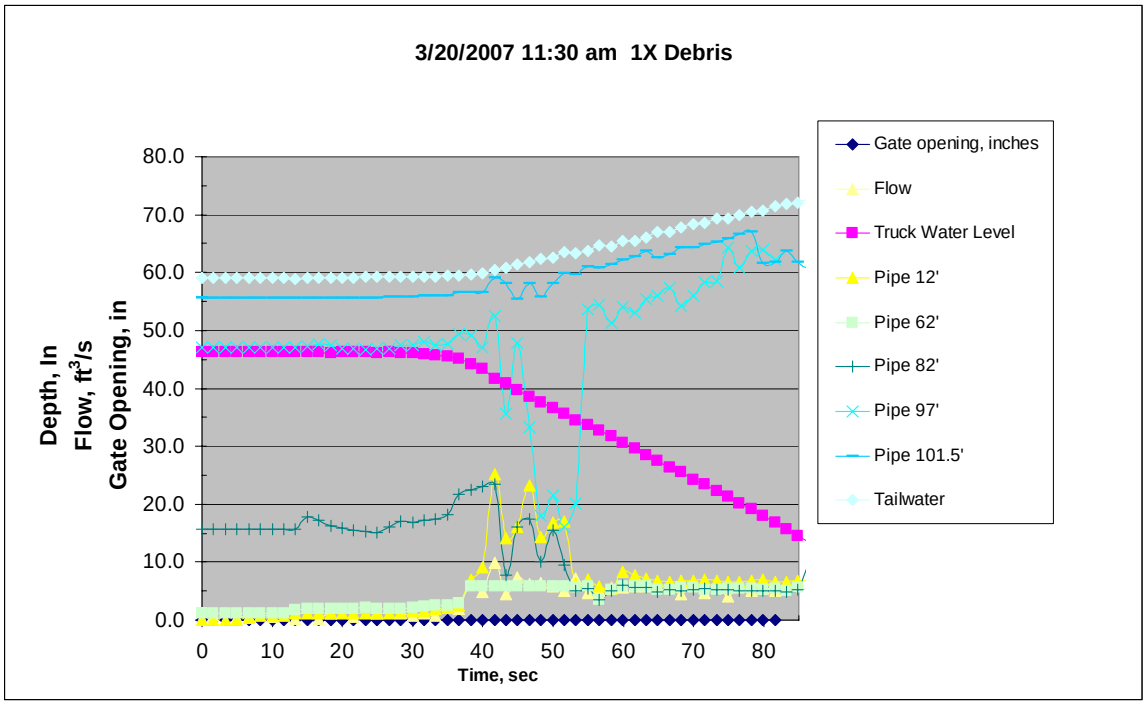

4/13/2007 11:30 am 0 Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

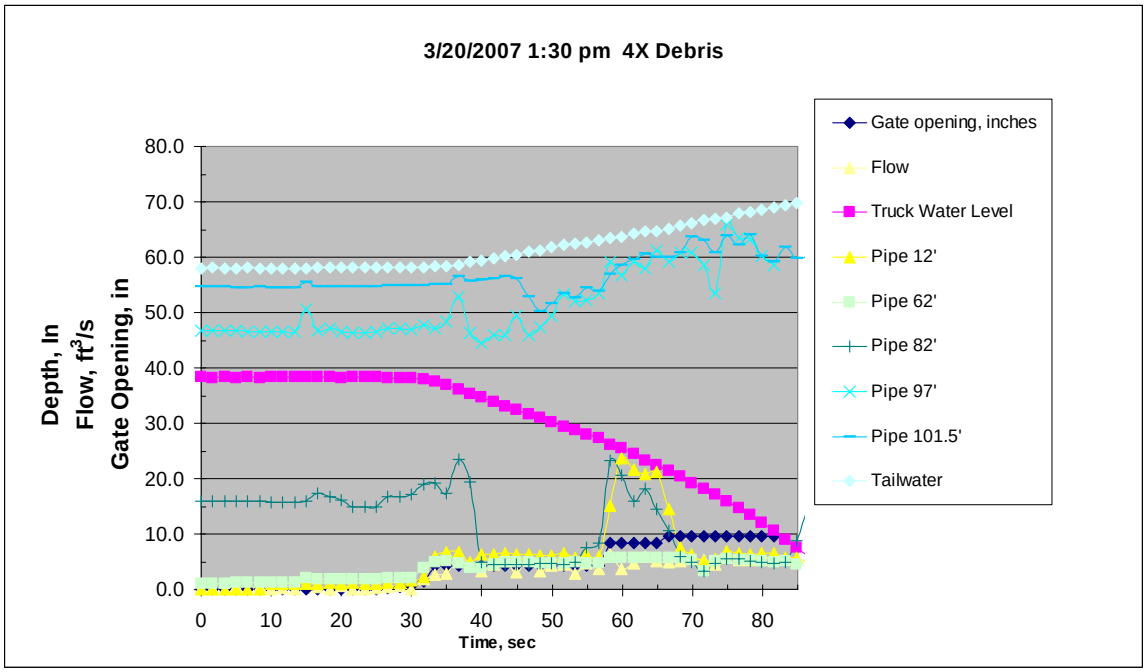

4/16/2007 10:00 am 0 Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

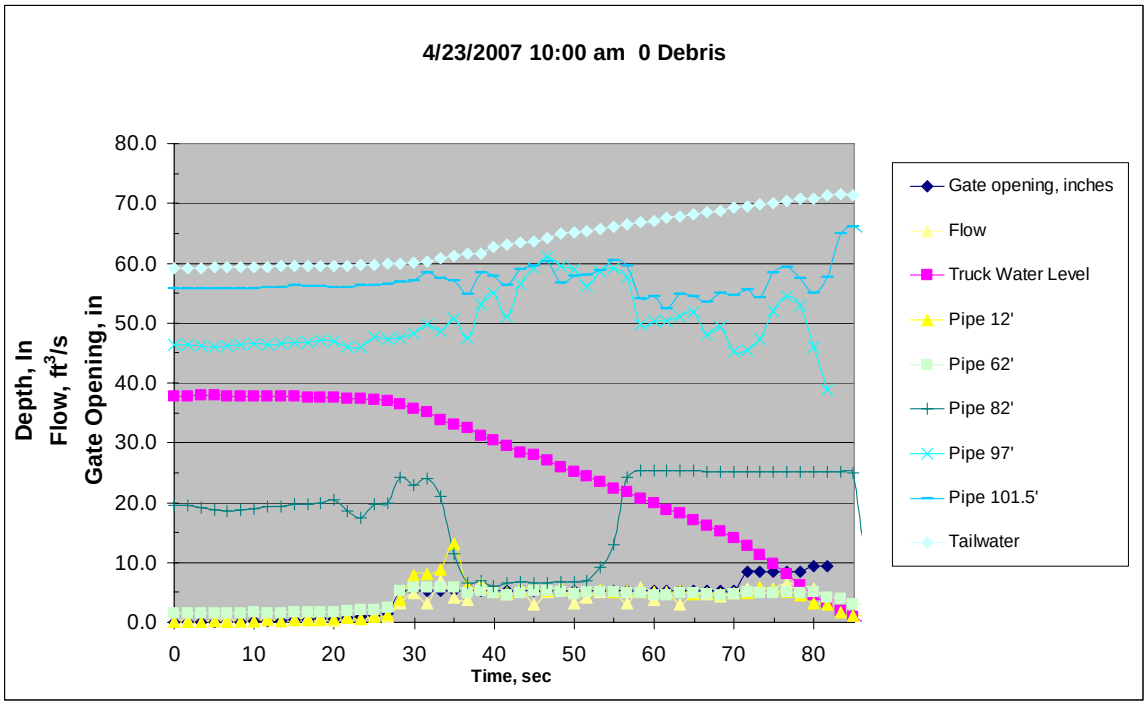

4/16/2007 11:30 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

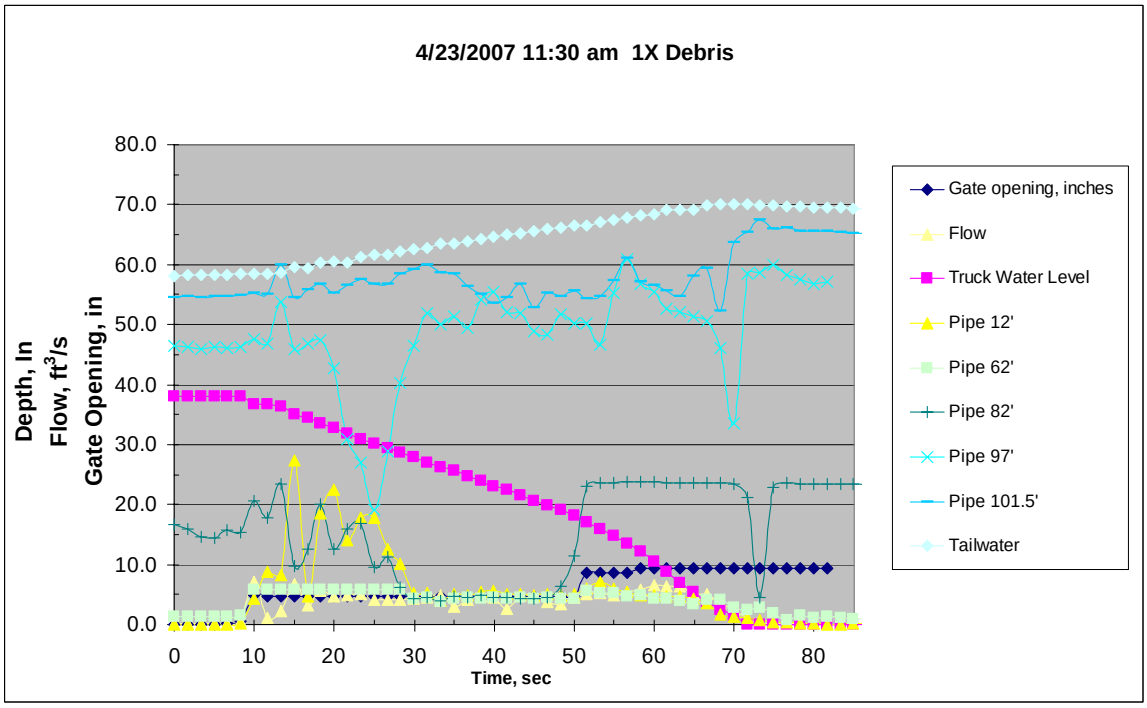

4/16/2007 11:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

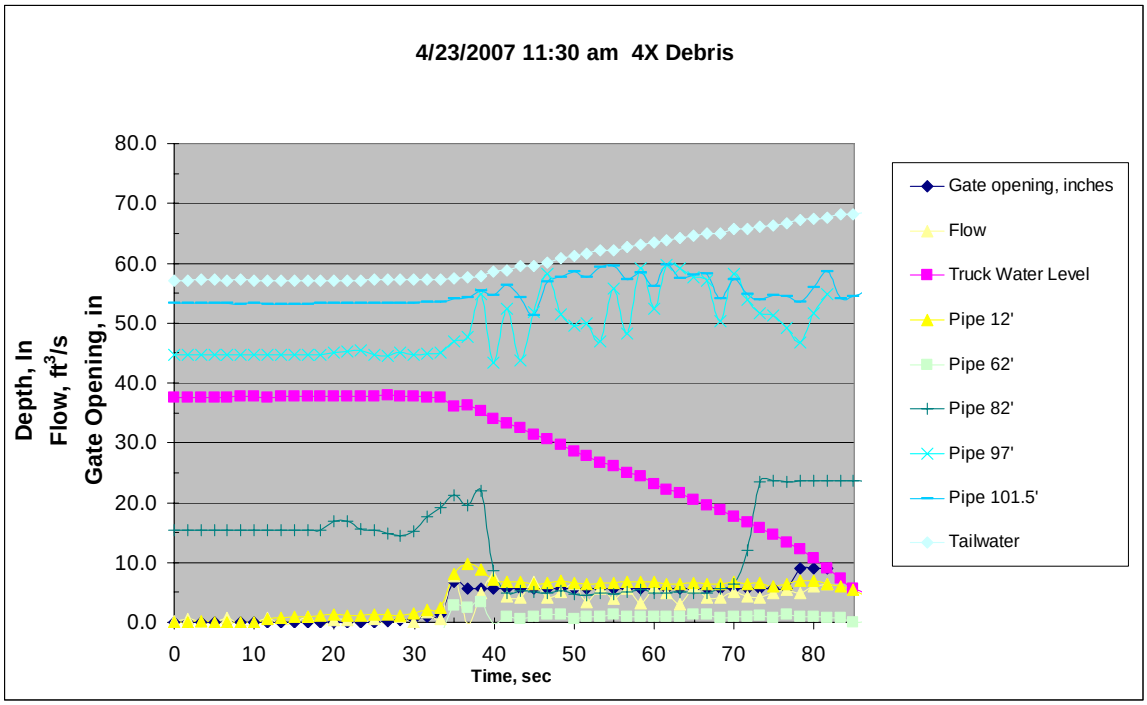

3/20/2007 10:00 pm 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

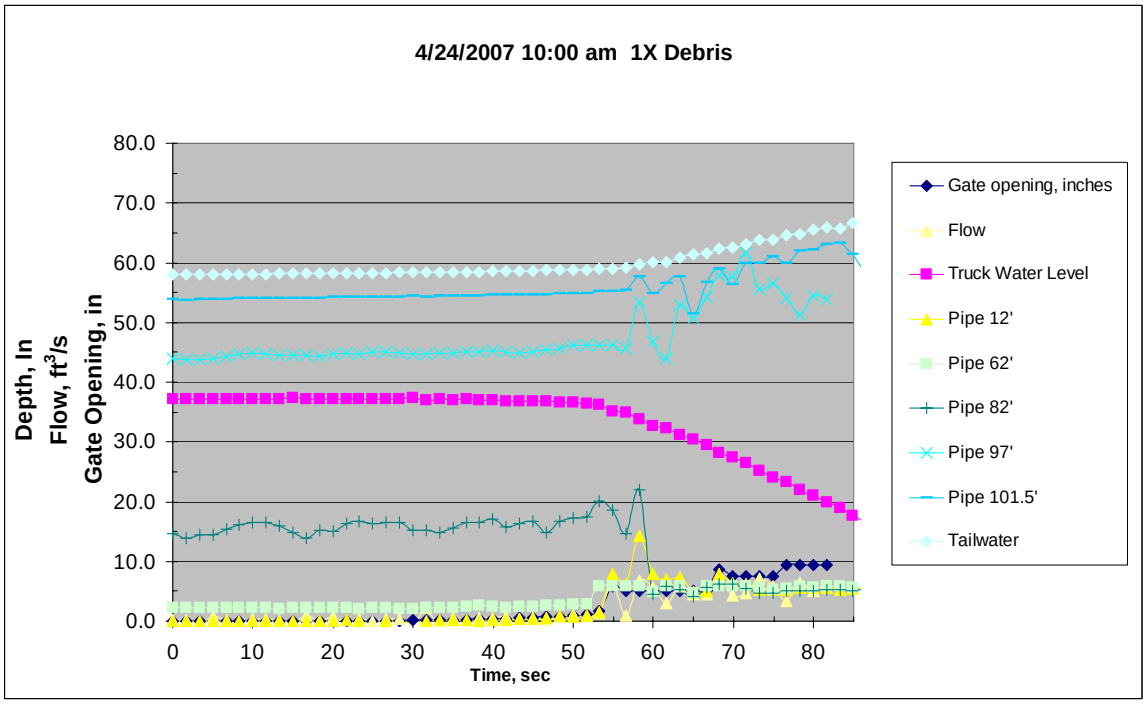

3/20/2007 11:30 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

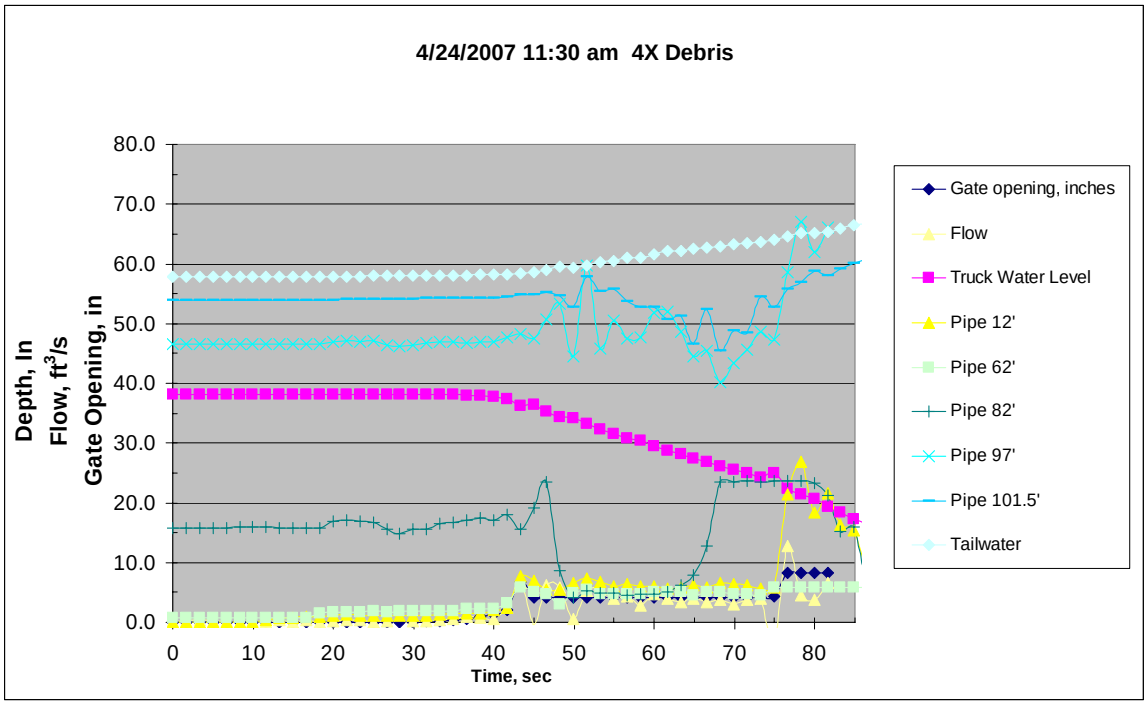

3/20/2007 1:30 pm 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

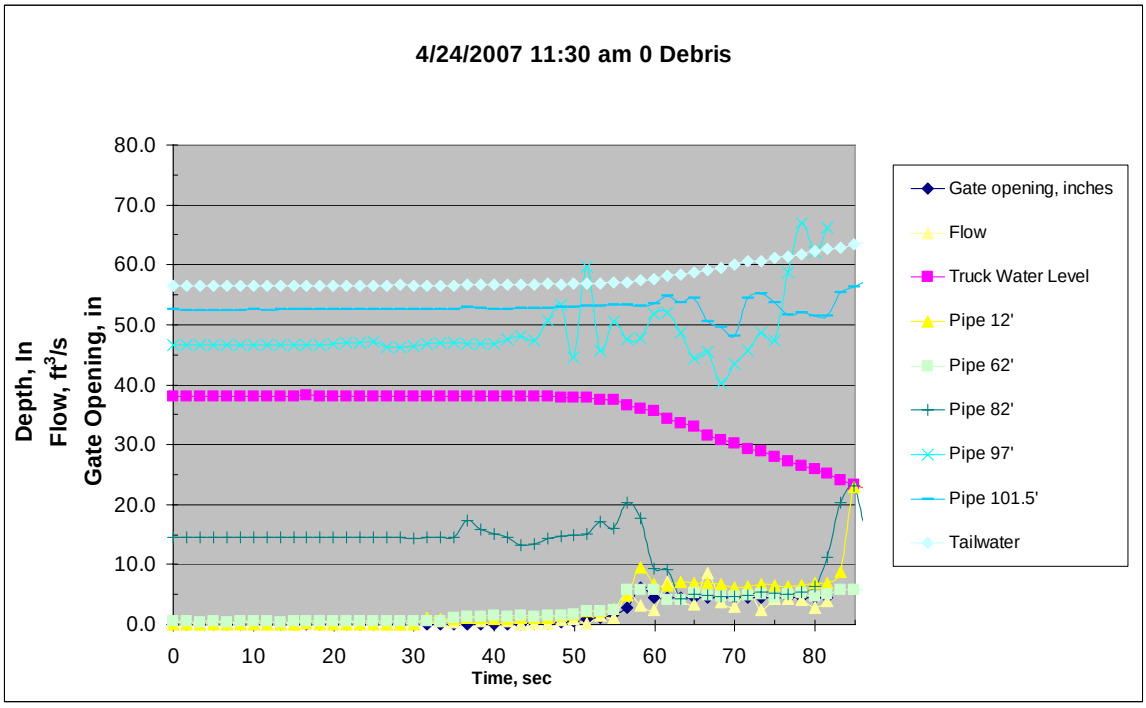

4/23/2007 10:00 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

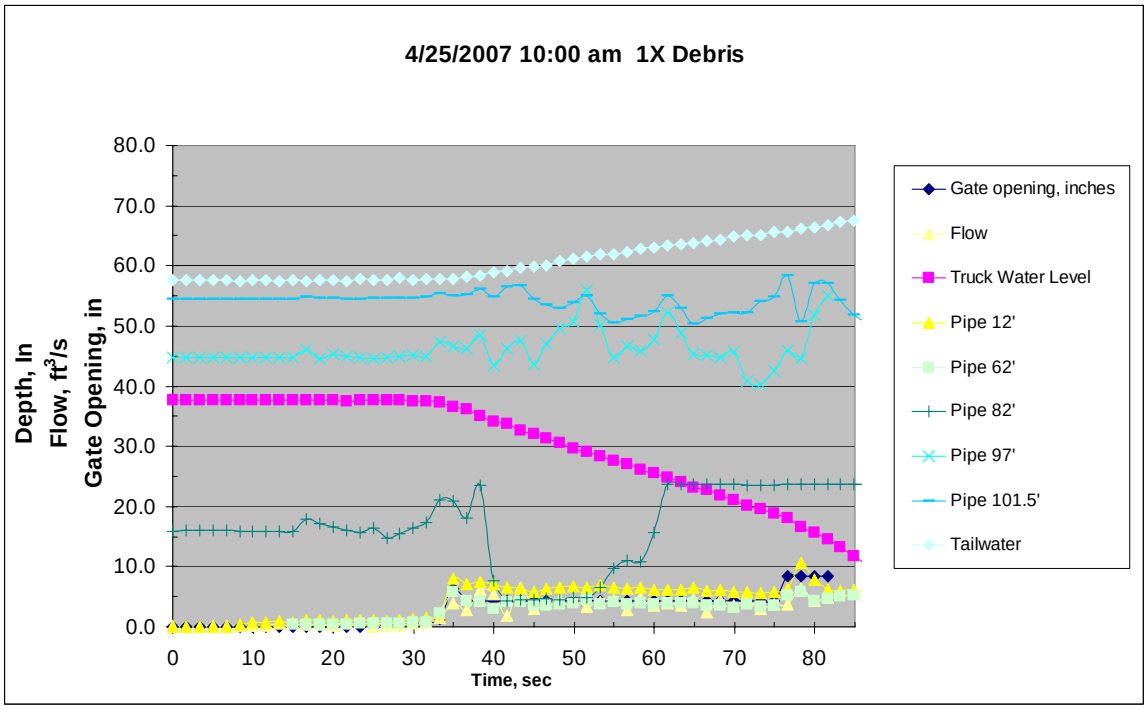

4/23/2007 11:30 am 1X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

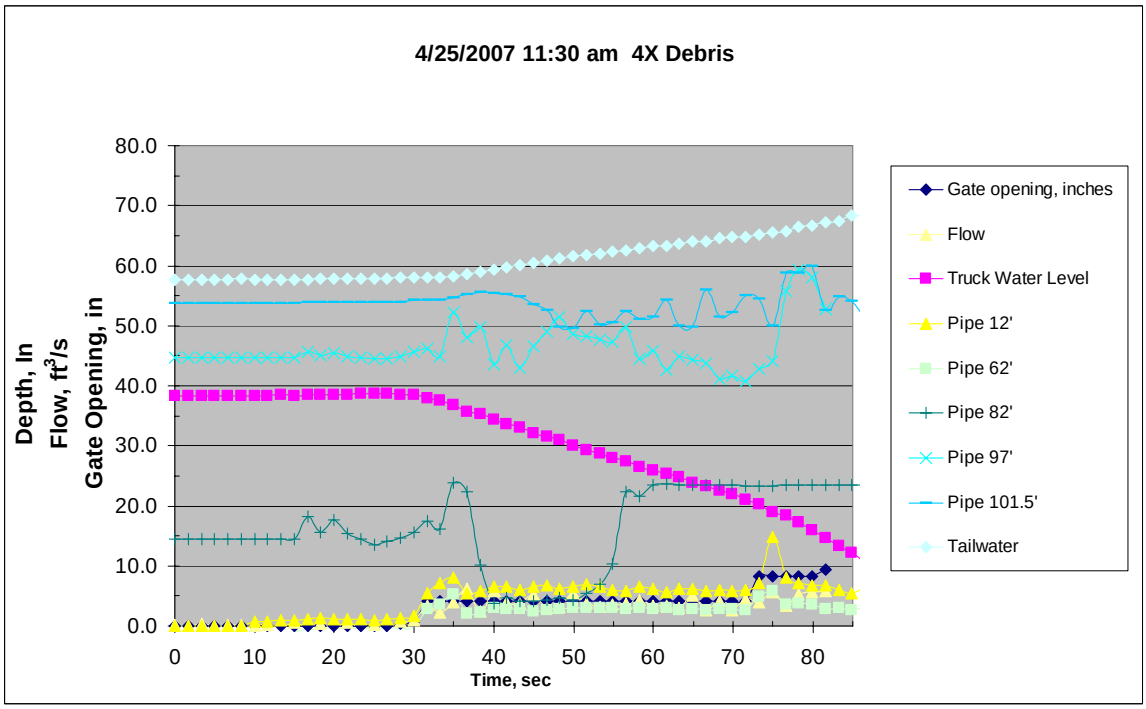

4/23/2007 11:30 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

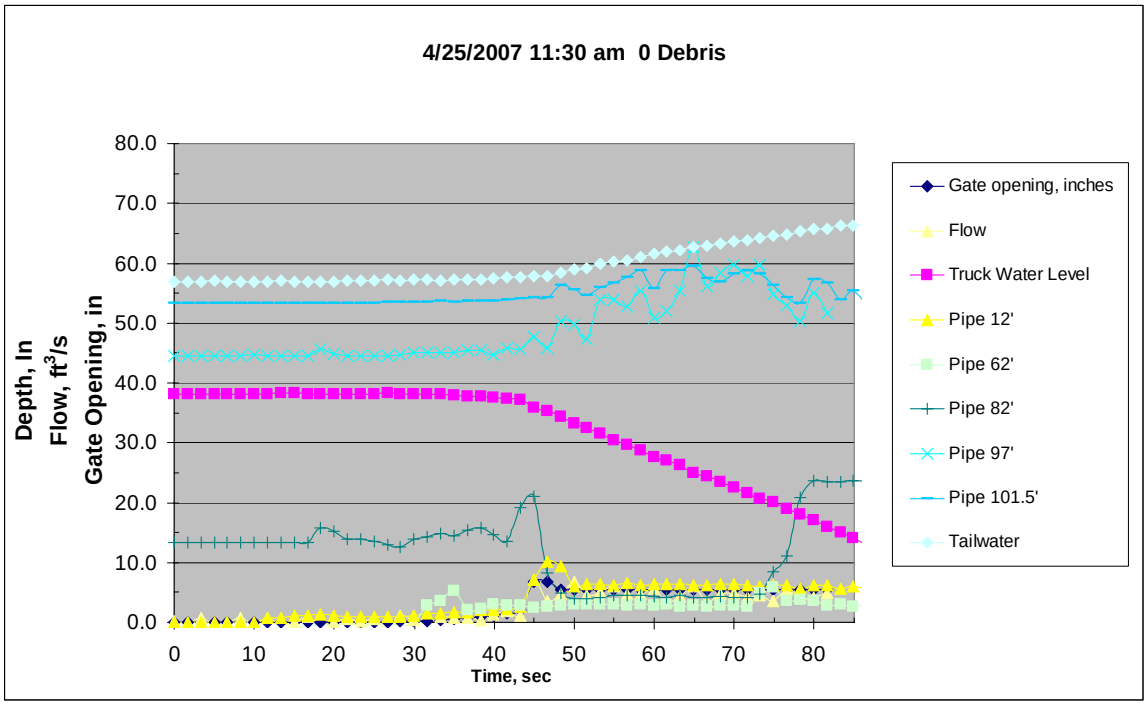

4/24/2007 10:00 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

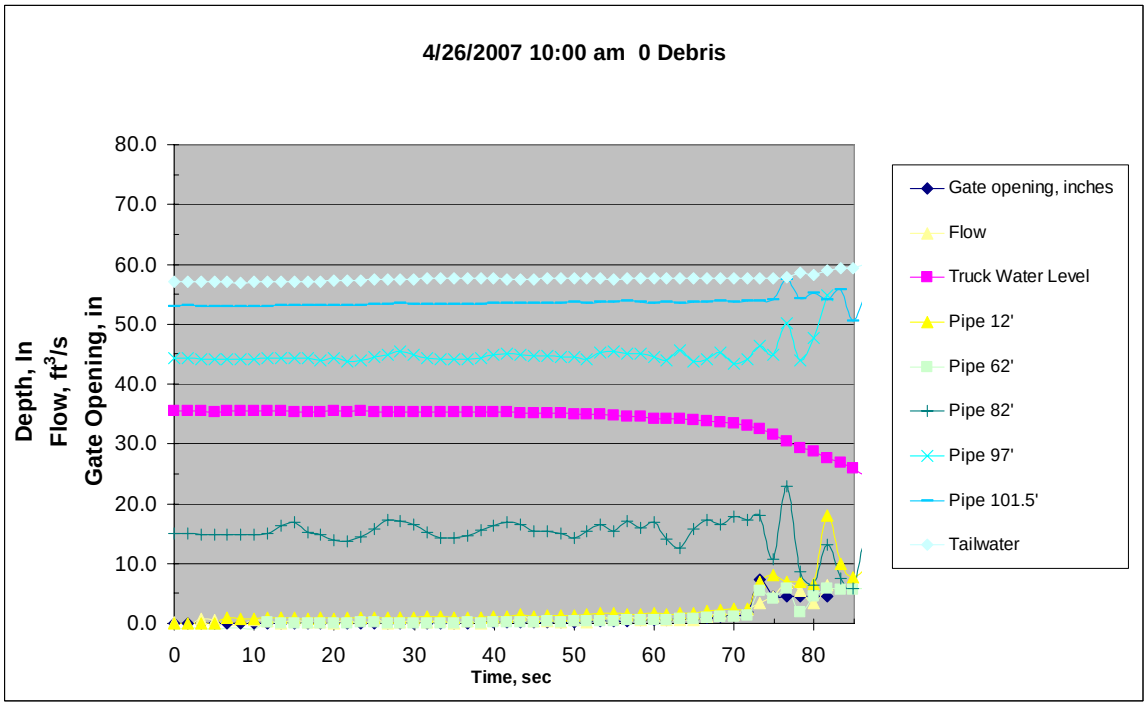

4/24/2007 11:30 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

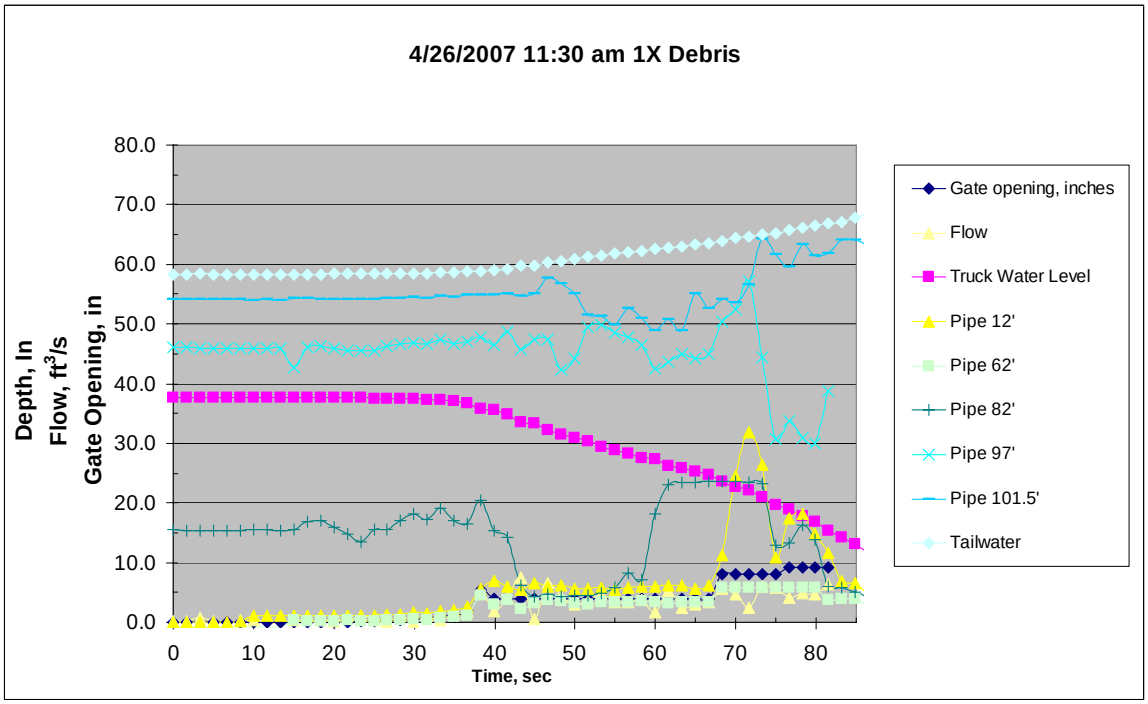

4/24/2007 11:30 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

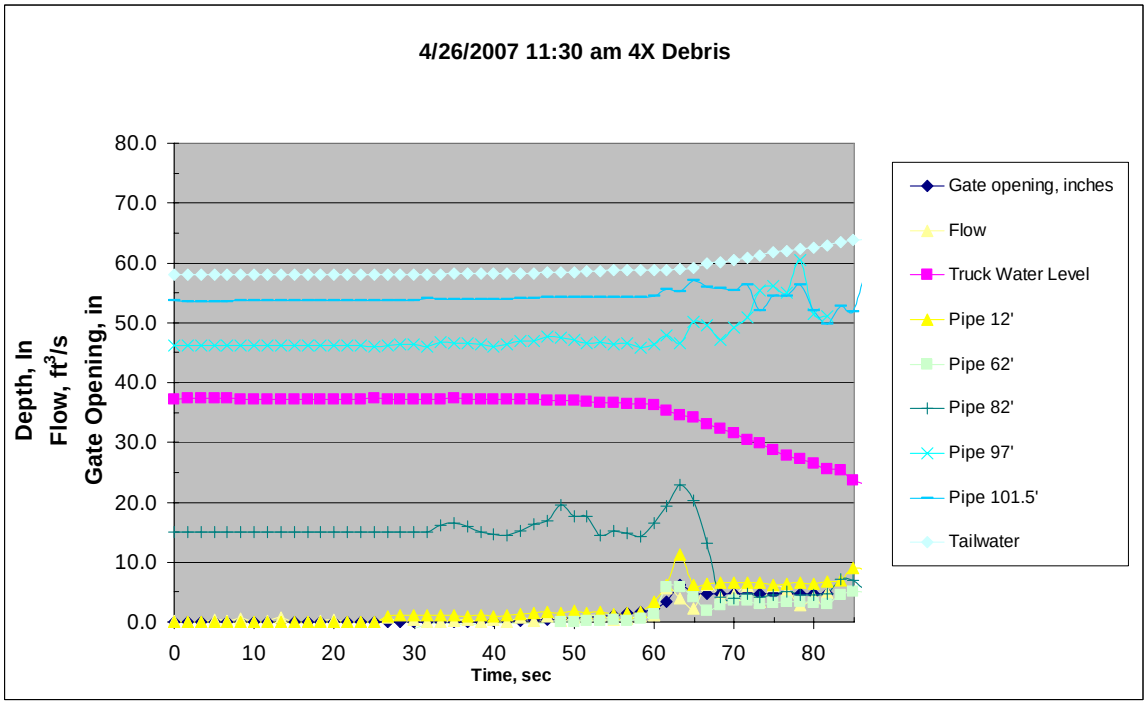

4/25/2007 10:00 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

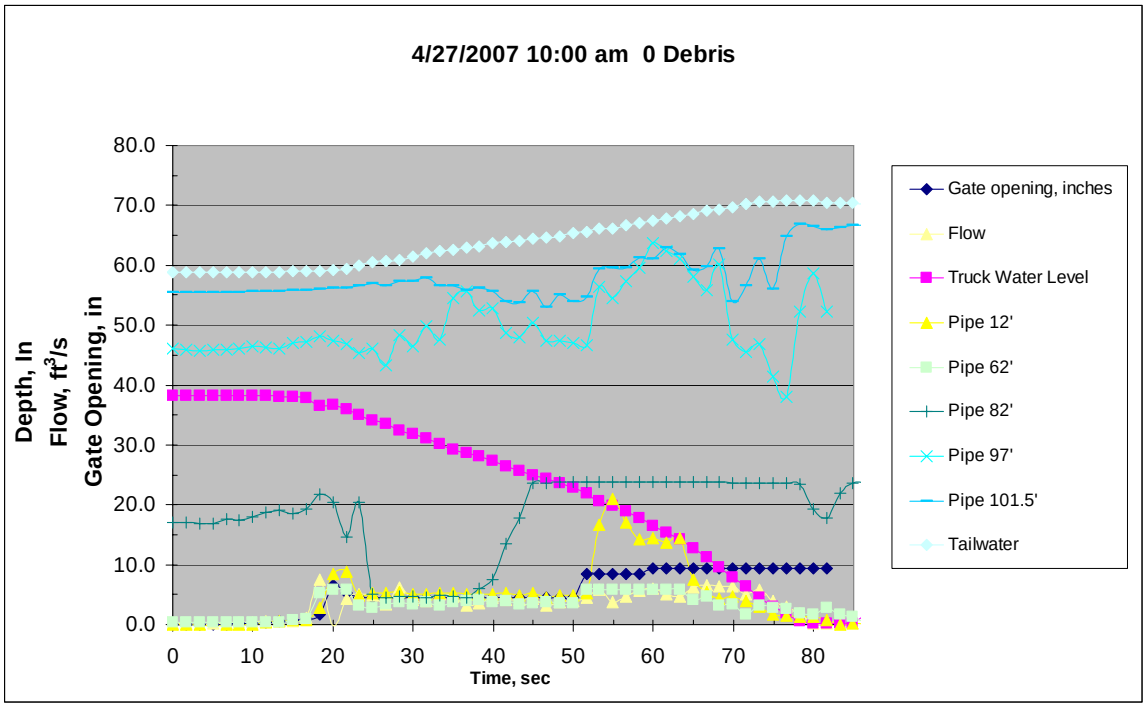

4/25/2007 11:30 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

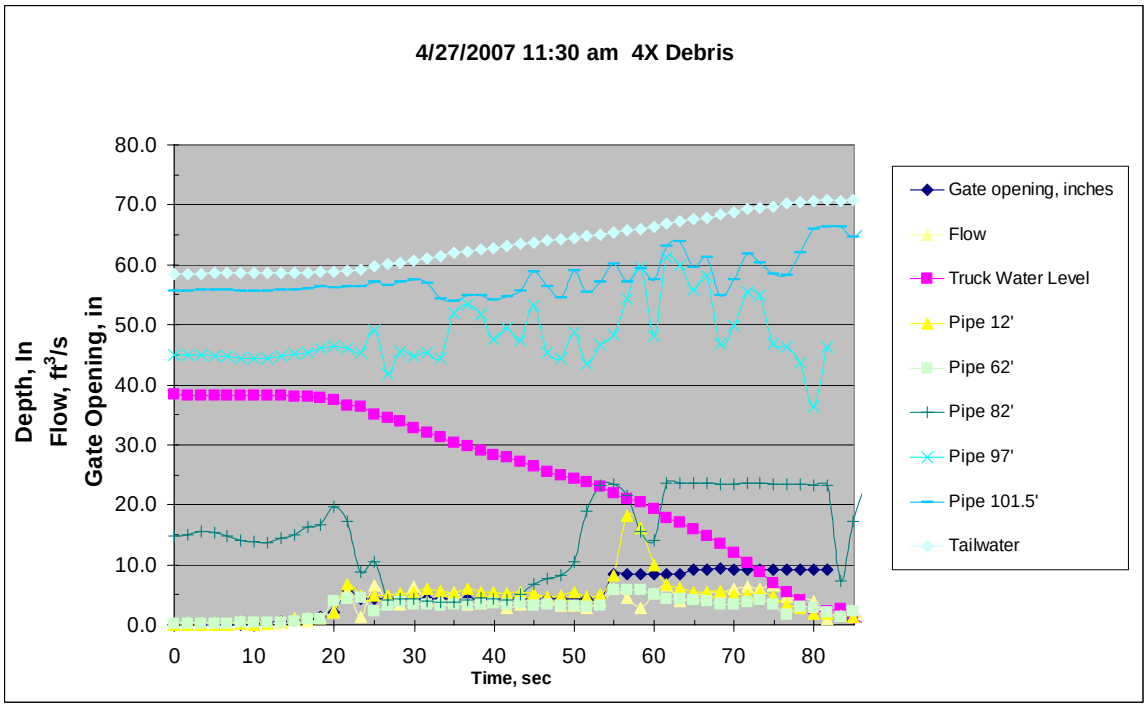

4/25/2007 11:30 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater

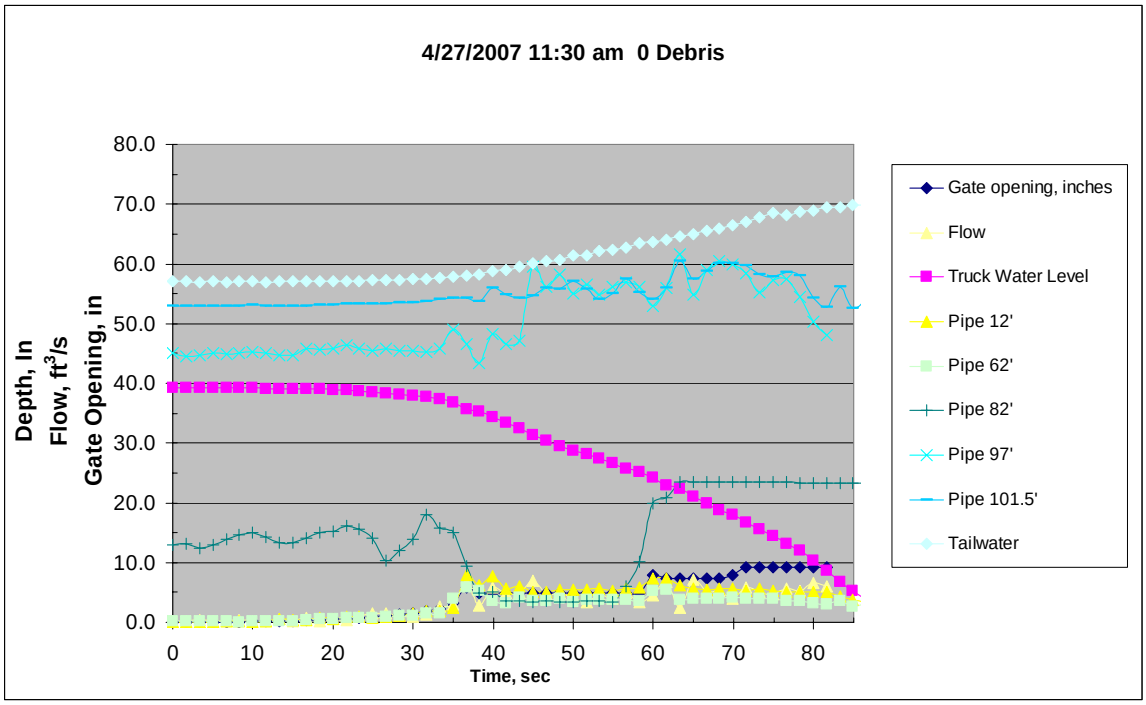

4/26/2007 10:00 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater


4/26/2007 11:30 am 1X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater


4/26/2007 11:30 am 4X Debris
Depth, In
Flow, ft³/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater


4/27/2007 10:00 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater


4/27/2007 11:30 am 4X Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater


4/27/2007 11:30 am 0 Debris
Depth, In
Flow, ft3/s
Gate Opening, in
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50
60
70
80
Time, sec
Gate opening, inches
Flow
Truck Water Level
Pipe 12'
Pipe 62'
Pipe 82'
Pipe 97'
Pipe 101.5'
Tailwater