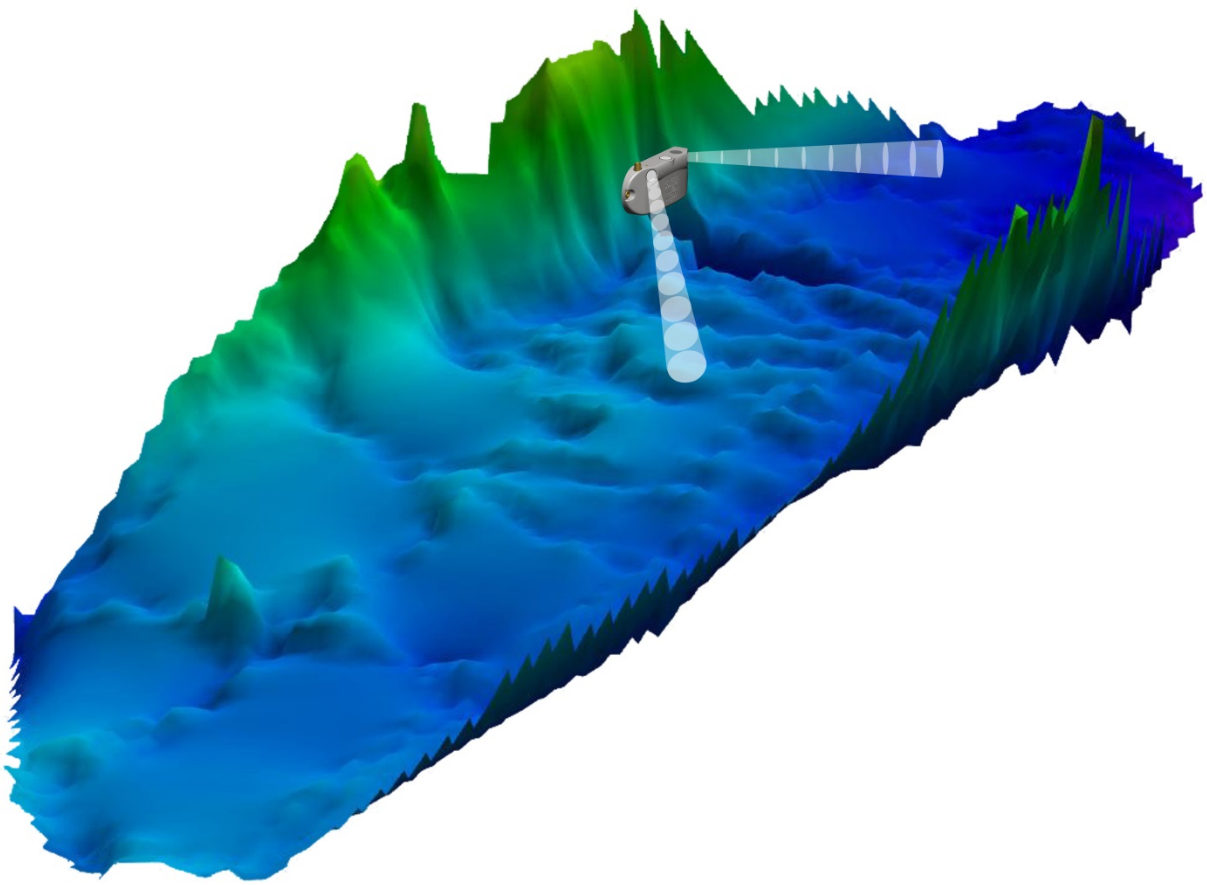
# Acoustic Doppler Velocity Meter

# Site Requirements



Version 2.0, April 2015

Title: Acoustic Doppler Velocity Meter Site Requirements

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Methodology: Acoustic Doppler Velocity Meter

Instruments: Argonaut SL500
SL3G1500, SL3G3000
IQPlus, IQStandard, IQPipe

**Revision History**

| Version | Date | Source | Description for Change |
|---|---|---|---|
| 2.0 | April 09, 2015 | Original Release | |
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# Terminology Definitions

**ADCP:** Acoustic Doppler Current Profiler

**ADVM:** Acoustic Doppler Velocity Meter

**Critical flow:** Froude number has a value of 1.0. The flow depth at critical flow is referred to as critical depth. This flow depth represents the minimum specific energy for a given discharge.

**Froude Number:** $Fr^2 = \dfrac{\alpha Q^2 B}{g A^3}$

where
Q = Discharge ($m^3/s$)
B = Top width of stream (m)
g = Gravitational acceleration (9.81 $m/s^2$)
A = Cross-sectional area ($m^2$)

**$h_c$:** Critical flow depth

**Headwater:** Headwater is the water elevation upstream of the culvert inlet.

**HydroSurveyor:** The HydroSurveyorTM is a system designed to collect bathymetric, water column velocity profile, and acoustic bottom tracking data as part of a hydrographic survey. The two key components of the system are the HydroSurveyor Acoustic Doppler Profiler (ADP®) platform, and the powerful, yet user-friendly, data collection software. With the HydroSurveyor platform, SonTek is able to offer an exclusive 5-beam depth sounding device, with built-in navigation, full water column velocity (currents) profiling, full compensation for speed of sound (with the CastAway-CTD), and integrated positioning solution.

**Index Velocity:** Index Velocity Rating principle is based on a stable and well-defined relationship between a Measured Velocity and the computed Mean Velocity.

**Integrated Velocity:** Integrated (theoretical) velocity for open channel and pressure (pipe) flow are based on the Measured Velocity and Hydraulic Principles.

**Laminar flow:** Occurs at very low velocities. Rarely encountered in practice.

Characterized by $\dfrac{vR}{\mu} < 500$; v = velocity, R = hydraulic radius; μ = absolute viscosity with the value for water ≈ 1.14 x $10^{-3}$ $m^2/s$ for general design purposes.

**Left Bank:** Left bank is the channel bank that is on the left when facing downstream.

**Open channel flow:** Flow surface open to atmospheric pressure.

**Partial full flow:** Partial full flow occurs when the water surface is exposed to atmospheric pressure in the pipe.

**Pressure flow:** Pressure flow occurs when the pipe is flowing full and under hydraulic pressure.

**Reynolds' Number :** $\mathrm{Re}_{(Channel)} = \frac{\rho RV}{\mu}$

where ρ = Fluid density
R = Hydraulic Radius (m)
V = Velocity
μ = Absolute Viscosity

**Right Bank:** Right bank is the channel bank that is on the right when facing downstream.

**Steady non-uniform flow:** Flow conditions change in magnitude or direction over distance along the channel but do not change with time.

**Steady uniform flow:** Flow conditions do not change in magnitude or direction over distance along the channel or with time.

**Subcritical flow:** Flow characterized by low velocities, large depths, mild slopes, and a Froude number less than 1.0.

**Supercritical flow:** Flow characterized by high velocities, shallow depths, steep slopes, and a Froude number greater than 1.0.

**Tailwater:** Tailwater is the water elevation downstream of the culvert outlet.

**Turbulent flow:** Most common type of flow; $\frac{vR}{\mu} > 1000$

**Unsteady non-uniform flow:** The magnitude and direction of the flow may change from point to point and with time at every point.

**Unsteady uniform flow:** At a given instant in time the magnitude and direction of the flow at every point in the channel are the same, but will change with time.

# 1. Introduction

The application of Acoustic Doppler Velocity Meters (ADVM) has expanded to a diverse range of technical fields within hydrology, water engineering and coastal engineering. Some of the key technical fields where ADVM's technology is implemented are surface water runoff, flood management, storm water runoff, water distribution and sediment transport.

The availability of accurate real time discharge information is a key aspect in Water Resource and Flood Management processes. ADVM's enables the user to determine instantaneous discharge at a specific location based on accurate velocity measurements. The application of ADVM's in complex flow conditions has become the standard where the traditional stage discharge relationship method is not sufficient to accurately define a discharge relationship at a monitoring site. Accurate velocity measurements with ADVM not only improve the instantaneous discharge at a specific monitoring point, but it also improves the overall quality of Water Resource and Flood Management outcomes associated with the discharge calculations from ADVM.

SonTek ADVM's are capable of operating in a wide range of flow conditions with the ability to perform discharge calculations in both the Index Velocity or Theoretical Flow methods. SonTek ADVM range incorporates the latest Acoustic Doppler and flow calculation methodology based upon research work, technology enhancements and experience from previous generation instruments.

The site requirements for ADVM's is a vital aspect for the efficient operation of the instruments and this technical paper discusses in detail the requirements at various hydraulic structures and what the impacts will be on the ADVM operation and accuracy of velocity and stage measurements. The hydraulic structures that will be discussed in this technical paper consist of the following categories, but not limited to the application.

i.) Natural Channels

ii.) Artificial Channels

iii.) Bridge Piers

iv.) Pipe and Box culverts

v.) Pressure Pipe Flow

vi.) Partially Full Pipe Flow

# 2. SonTek ADVM's

The SonTek ADVM range is categorized into two groups, the Side Looking ADVM (SL) and the Up \ Down Looking ADVM (IQ) that is currently available for the hydrology, water engineering and coastal engineering market. The "*SonTek ADVM's*" section highlights some of the instrument specifications and operational principles and it is recommended that the user refer to instrument brochures and technical manuals for more complete description.

## 2.1 Instrument Range

### 2.1.1 SonTek-SL Series

Measurement principle is based on two acoustic beams each slanted at 25° off the instrument axis. The system measures velocity in a horizontal profile that is dived into multiple cells based on the user configuration. The profiling range of the SL series are the following

| Instrument | Minimum | Maximum | Cells |
|---|---|---|---|
| **SL500** | 1.5m | 120m | 10 |
| **SL1500 (3G)** | 0.2m | 20m | 128 |
| **SL3000 (3G)** | 0.1m | 5.0m | 128 |

with up to 10 cells for the SL500 and up to 128 cells for the SL1500 (3G) and SL3000 (3G) that can be incorporated along the horizontal beam based on user configuration. The X and Y velocity components measured at each multi-cell along the horizontal beam during profiling are used for developing the Index Velocity Types.

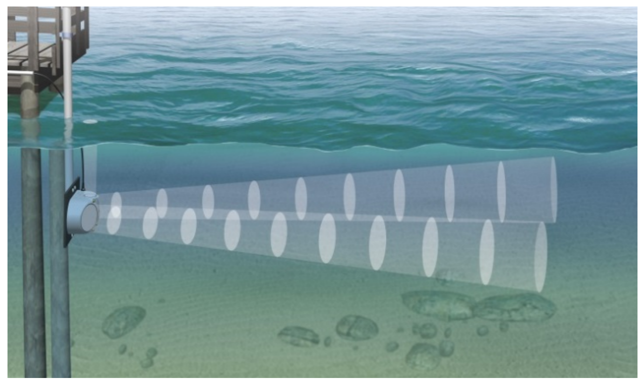


**Figure 1:** Application of SL500 in River or Harbor

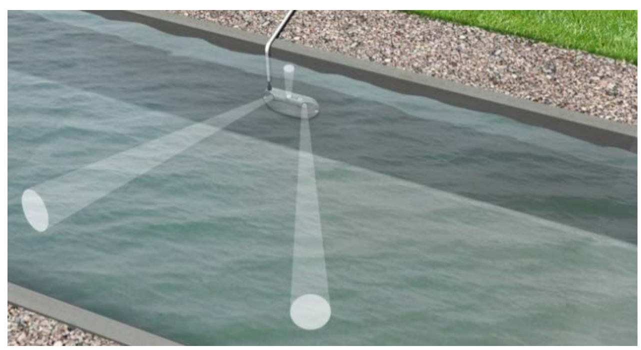


**Figure 2:** Application of SL3000 (3G) in irrigation canal.

### 2.1.2 SonTek-IQ Series

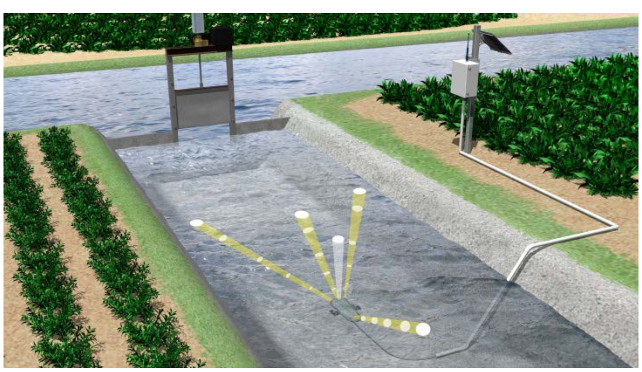


**Figure 3:** Application of IQ Plus in irrigation canal

Measurement principle is based on upstream and downstream acoustic beams along the axis each slanted at 25° off the vertical and two skew beams. The system makes use of SmartPulseHD that adapts the profiling technique, cell size and number of cells based on the flow conditions and water depth. The profiling range of the SonTek-IQ Series are the following,

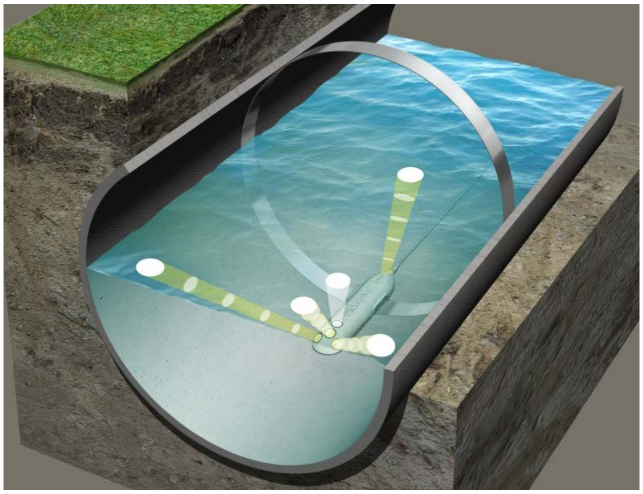


**Figure 4:** Application of IQ Pipe in storm water pipe

| Instrument | Minimum | Maximum |
|---|---|---|
| **IQ Plus** | 0.08m | 5.0m |
| **IQ Standard** | 0.08m | 1.5m |
| **IQ Pipe** | 0.08m | 5.0m |

with up to 100 cells in the "Along Axis Beams" based on depth and velocity conditions. The X and Y velocity components measured at each multi-cell along the beams during profiling are used for developing the Index Velocity Types (not applicable to IQ Standard).

It is important to note that although both the IQ Plus and IQ Pipe can be installed in either open channels or closed conduits, the theoretical pipe flow algorithms only exist in the IQ Pipe system and theoretical open channel flow algorithms only exist in the IQ Plus (and IQ Standard). If an IQ Pipe is installed in an open channel, or an IQ Plus is installed inside a pipe, flow (volumetric discharge) must be computed outside of the system using the index velocity (rating) method. Flow algorithms are dependent on instrument type. The table below describes the flow algorithms based on instrument type, with Theoretical Flow Algorithm (T) and Index Velocity Rating (R).

| Flow Algorithm | IQ Standard | IQ Plus | IQ Pipe |
|---|---|---|---|
| **Open Channel All** | | T/R | R |
| **Closed Conduits All** | | R | T/R |
| **Open Channel Trapezoid** | T | T/R | R |
| **Open Channel Irregular** | T | T/R | R |

## 2.2 Principle of Operation

The key principle of ADVM's operation is the assumption that all acoustic transducers are exposed to the exact same flow conditions within the flow extent and therefore **homogeneous** flow conditions. **Homogeneous** flow conditions implies that the following hydraulic conditions are the same in the effective measurement volume,

i.) Flow type is Uniform

ii.) Subcritical Flow Regime

## 2.3 Discharge Calculation

SonTek ADVM's measure water velocity by using the acoustic doppler principle and the X and Y velocity components measured at each multi cell along the beams during profiling are used for developing a mean "Index Velocity" and or "Theoretical Velocity".

The discharge calculations for SonTek ADVM instruments are based on the mean “Index Velocity” and “Integrated Velocity (Theoretical)” developed from Measured Velocity and the following sections give a brief description of the calculation process.

### 2.3.1. Index Velocity

The Index Velocity Rating principle is based on a stable and well-defined relationship between a Measured Velocity and the computed Mean Velocity. Mean Velocity is calculated from the total discharge and the submerged area within the channel section. The relationship between the Measured Velocity and Mean Velocity is a function of the velocity profile, cross-stream velocity, velocity distribution and stage. The relationship in its simplest form can be written with the following variables as a function,

| | |
|---|---|
| index velocity | $V_m = a + V_I b$ |
| index velocity and stage | $V_m = a + V_I(b + cH)$ |

The relationship of the velocity component for the Index Velocity Rating can be accurately defined by the X component of the Measured Velocity in ideal flow conditions. Ideal flow conditions seldom occur in natural or artificial channels and for this reason SonTek has developed a range of Index Velocity Types based on actual flow conditions measured with ADVM instruments. The Index Velocity Types available allows the user to determine,

- the index velocity that best define the relationship with Mean Velocity
- other velocity components that may impact the relationship with Mean Velocity

### 2.3.2. Integrated Velocity (Theoretical)

The integrated (theoretical) velocity for open channel and pressure (pipe) flow are based on the Measured Velocity from the ADVM and Theoretical Flow Principles. The Measured Velocity is applied with Theoretical Flow Principles to develop an integrated velocity across the submerged area within the channel section.

V I T A L

The Integrated Velocity method for open channel and pressure (pipe) flow is dependent on ideal flow conditions due to the following key factors,

- The methodology applied in developing integrated velocity is based on Theoretical Flow Principles with the following assumptions for open channel and pressure (pipe) flows,

  **Open Channel Flow**

  i.) Flow conditions are steady uniform flow.

  ii.) Flow is homogenous

  iii.) The flow regime is subcritical.

  iv.) ADVM is positioned in the channel section where the maximum velocity occurs.

**Pressure (pipe) flow**

i.) Pressure (pipe) flow conditions are laminar.

- The measurement profile of the ADVM comprises only a portion of the overall channel section.

FLAG

The development of accurate mean integrated velocity will be impacted if the flow conditions do not comply with the above mentioned factors and site requirements that are further stipulated in this document.

The application of the integrated velocity method for discharge calculation is not applicable to all flow conditions and the user need to perform comprehensive evaluation of the site conditions and other factors that may impact on the ADVM measurement accuracy. Depending on the monitoring objectives and site conditions, the Index Velocity Method could be the preferred method over the Integrated Velocity method for discharge calculations.

# 3. Hydraulic Conditions

Hydraulic conditions are unique at each monitoring location and depending on what type of hydraulic structure are used as a platform for ADVM measurements, there are specific criteria that need to be considered during each installation. The "*Hydraulic Conditions*" section highlights some of the basic hydraulic concepts applicable at each of the deployment scenarios discussed in this document. It is recommended that further literature is referenced for detailed discussion of hydraulic principles involved and that this section serves more an overview of the methodology.

## 3.1. Open Channel Flow

The main state of flow for open channel flow conditions are categorized under laminar flow, transitional flow and turbulent flow. Because flows in natural rivers are always in a turbulent state, methods analyzing turbulent flow conditions are presented in this document. Flow conditions are further classified by the "Flow Type" and "Flow Regime" that exists for certain flow extent and is described with the following graphical representations.

### Flow Type

**Steady uniform flow:** Flow conditions do not change in magnitude or direction over distance along the channel or with time.

**Steady non-uniform flow:** Flow conditions change in magnitude or direction over distance along the channel but do not change with time.

**Unsteady uniform flow:** At a given instant in time the magnitude and direction of the flow at every point in the channel are the same, but will change with time.

**Unsteady non-uniform flow:** The magnitude and direction of the flow may change from point to point and with time at every point.

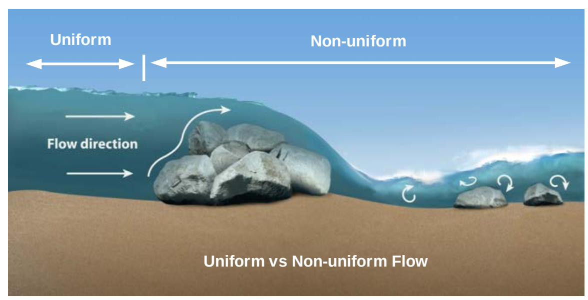



**Figure 5:** Uniform and Non-uniform flow conditions

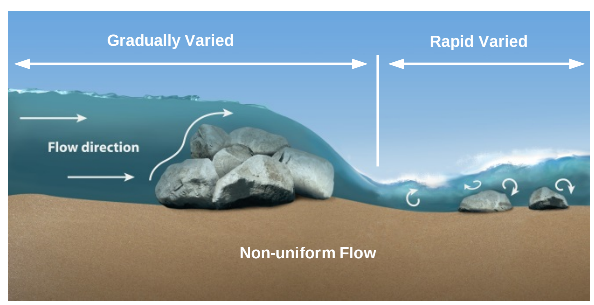



**Figure 6:** Types of Non-uniform flow conditions

### Flow Regime

**Critical flow:** Froude number has a value of 1.0. The flow depth at critical flow is referred to as critical depth ($y_c$). This Flow depth represents the minimum specific energy for a given discharge.

**Subcritical flow:** Flow characterized by low

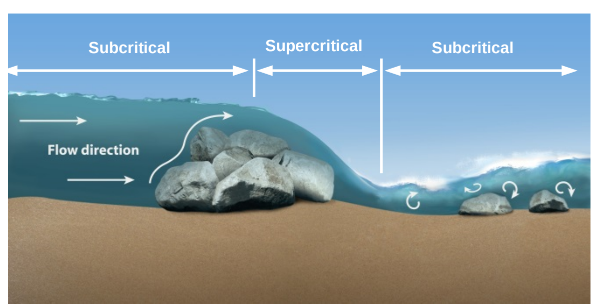



**Figure 7:** Classification of Flow Regime

velocities, large depths, mild slopes, and a Froude number less than 1.0.

**Supercritical flow:** Flow characterized by high velocities, shallow depths, steep slopes, and a Froude number greater than 1.0.

The Froude number is defined by the following equation,

**Froude Number:** $Fr^2 = \frac{\alpha Q^2 B}{g A^3}$

where Q = Discharge ($m^3/s$)
B = Top width of stream (m)
g = Gravitational acceleration (9.81 $m/s^2$)
A = Cross-sectional area ($m^2$)

## 3.2. Control

Controls in natural or artificial channels are either classified as a physical feature (section control) or combination of channel roughness, slope and reach properties (channel control). The effects of controls in natural or artificial channels govern the water surface profile and magnitude of velocity upstream of the control and the extent of prevalence on flow conditions are dependent on the following factors,

i.) Physical extent of controlling feature

ii.) Channel reach properties

iii.) Magnitude of discharge

### Natural Section Controls

Natural controls can consist of either lose boulders or a defined rock formation and can be further classified under stable and unstable cross section.

The geometry of natural control can be impacted by vegetation and sediment transport and this affects the stability of the cross section geometry and the prevalence on water surface profile and magnitude of velocity upstream of the control.

**Figure 8:** Tufa Dams (photograph by Sean Lawrie, DLRM, Northern Territory, Australia)


**Figure 9:** Multi Notch Crump Gauging Weir
(photograph by Jackie van Bosch, DWA, South Africa)

**Artificial Section Controls**

Artificial controls can consist of any man made feature from gauging weirs, bridges, water locks, culverts, etc.

The cross sectional geometry of artificial controls can also be impacted by vegetation and sediment transport, but the impact can be reduced by incorporating the effects during the design stages and with regular maintenance.

**Drawdown**

Drawdown occurs when the flow approaches the crest of the section control and the water velocity increases gradually to point where the flow regime changes from subcritical to critical above the crest. The water velocity continues to increase beyond the crest changing the flow regime from critical to supercritical flow.

In the case of artificial gauging weirs the drawdown zone is defined by the distance from the crest of the gauging weir to a point 4 times the flow depth (maximum flow capacity) at the gauging weir upstream.

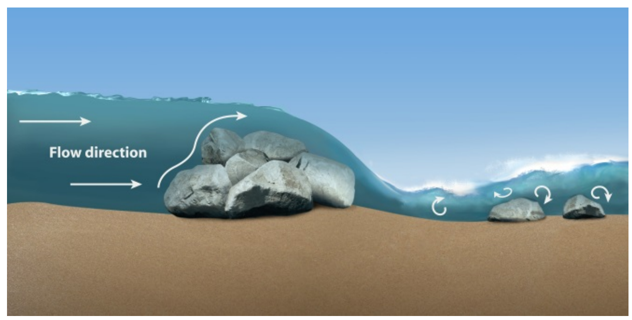



**Figure 10:** Water surface profile drawdown

## 3.3. Bridges

The hydraulic principles of open channel flow are also applicable to flow at bridges with the following factors that need to be taken into account when evaluating bridges as a potential platform for ADVM instruments.

i.) Section or channel control downstream of bridge is the controlling feature in the river reach
ii.) Bridge section is the controlling feature in the river reach
iii.) Flow disturbance caused by bridge piers and or embankments.

### Tranquil Flow (subcritical)

Tranquil or subcritical flow conditions at a bridge exists when the bridge section is not the dominant feature in the river reach but a section or channel control downstream acts as the controlling feature governing the water surface profile.

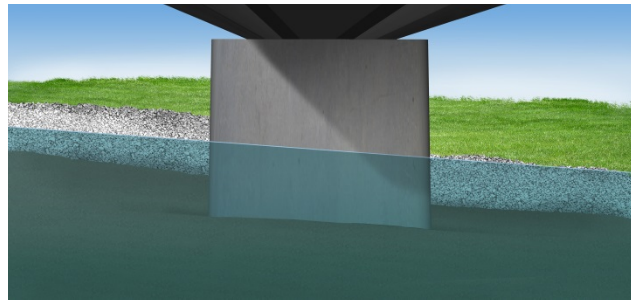


**Figure 11:** Tranquil flow conditions at bridge

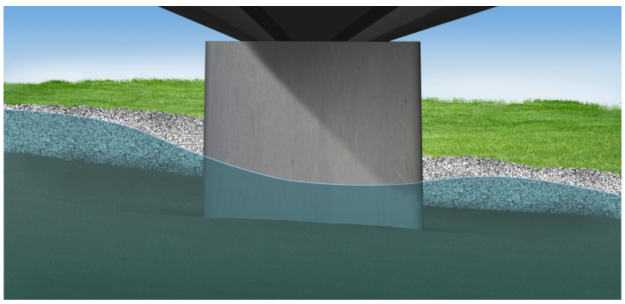


**Figure 12:** Rapid flow conditions at bridge

### Rapid Flow (supercritical)

Rapid flow conditions at a bridge exist when the bridge section acts as the controlling feature in the river reach and the flow regime changes from subcritical to supercritical at the bridge location.

### Flow Disturbance

Flow disturbance is caused by placing an object in the path of approaching flow and in the case of bridges, bridge piers and embankments can create flow disturbance.

The following equation can be used to define the extent of the flow disturbance caused by bridge piers and or embankments.

$$d = c \times (b \times x)^{0.5}$$

where

- d = lateral distance from pier centerline to edge of wake turbulence zone;
- c = form factor for pier shape (0.62 round-faced pier and 0.81 rectangular-faced pier);
- b = effective pier width;
- x = distance from ADVM to upstream face of pier

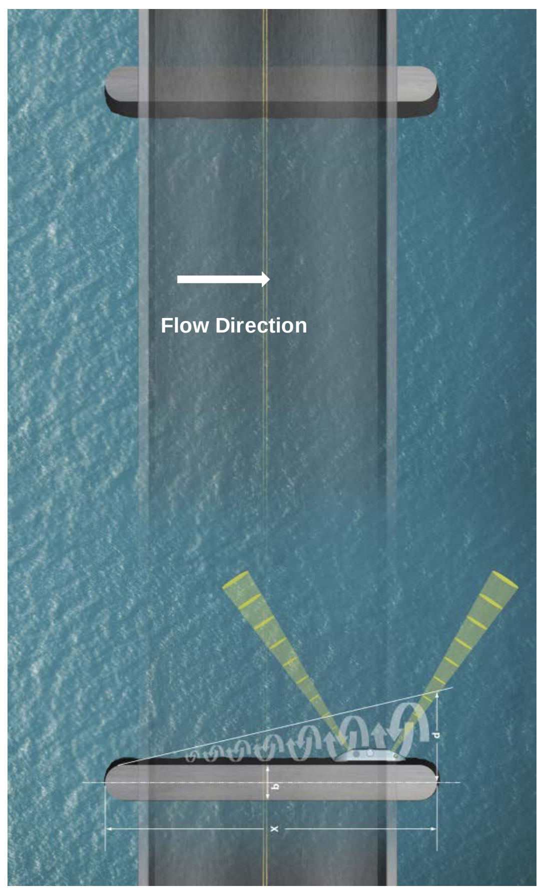



**Figure 13:** Flow disturbance at bridge pier

## 3.4. Culverts

The hydraulic principles of open channel flow are also applicable to flow in culverts with the following factors that need to be taken into account when evaluating culverts as a potential platform for ADVM instruments.

i.) Culvert inlet as the controlling feature.

ii.) Culvert outlet as the controlling feature.

iii.) Flow disturbance caused by culvert entrance.

### Critical Depth at Inlet

The culvert inlet is the controlling feature and the flow regime change from subcritical to supercritical with critical depth at the inlet of the culvert. The critical flow depth is indicated by $h_c$ on the diagram.

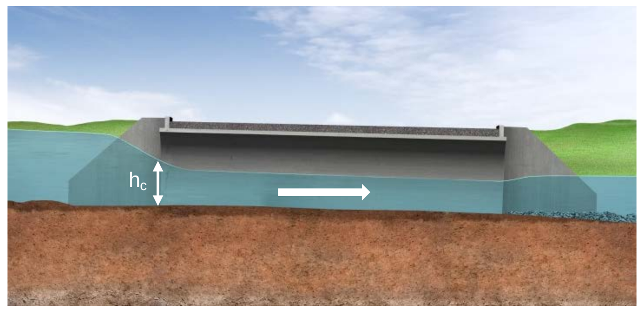



**Figure 14:** Critical depth at inlet of Culvert

### Critical Depth at Outlet

The culvert outlet is the controlling feature and the flow regime change from subcritical to supercritical with critical depth at the outlet of the culvert. The critical flow depth is indicated by $h_c$ on the diagram.


**Figure 15:** Critical depth at outlet of Culvert

### Tranquil flow Throughout

Flow regime is subcritical and flow conditions are consistent throughout the culvert. This flow condition is the most stable although sediment deposition and or aquatic growth is likely to occur when the ratio of headwater to tailwater elevation approaches 1 for prolonged periods.


**Figure 16:** Tranquil flow throughout Culvert

**Figure 17:** Submerged Outlet at Culvert

### Submerged Outlet

Pressure flow is occurring in the culvert and the flow conditions at the outlet could be highly turbulent depending on the available headwater and tailwater at the culverts inlet and outlet. Sediment deposition and or aquatic growth are likely to occur when the ratio of headwater to tailwater elevation approaches 1 for prolonged periods.

### Rapid flow at Inlet

The culvert inlet is the controlling feature and the flow regime change from subcritical to supercritical at the inlet of the culvert. The flow conditions inside the culvert could be unstable with high velocities especially at the inlet depending on the available headwater.

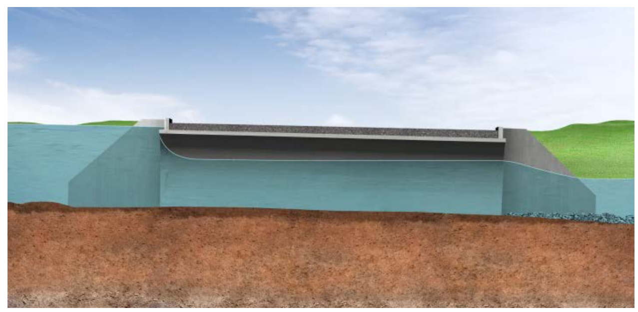


**Figure 18:** Rapid low at Culvert inlet

**Figure 19:** Full flow free outflow at Culvert

### Full Flow Free Outflow

Pressure flow is occurring in culvert. Sediment deposition and or aquatic growth are likely to occur when the ratio of headwater to tailwater elevation approaches 1 for prolonged periods.

## 3.5. Pipe Flow

### 3.4.1. Partial Full Flow

The hydraulic principles of open channel flow are also applicable to flow in partially full pipes with the following factors that need to be taken into account when evaluating pipes as a potential platform for ADVM instruments.

i.) Hydraulic structures acting as control features.

ii.) Flow disturbance caused by hydraulic structures.

iii.) Convergence and divergence of different size pipes.

iv.) Jet flow generated by valves

### 3.4.2. Pressure Flow

The main state of pressure flow for pipe flow conditions are categorized under laminar flow, transitional flow and turbulent flow. Because most flows in pipes are in a turbulent state the methods analyzing turbulent flow conditions are presented in this document.

Whether a flow will result in laminar or turbulent low is primarily determined by the Reynolds number,

**Reynolds' Number :** $\mathrm{Re}_{(Channel)} = \dfrac{\rho R V}{\mu}$

where
- ρ = Fluid density
- R = Hydraulic Radius (m)
- V = Velocity
- μ = Absolute Viscosity

- Laminar for Re < 2000
- Transitional between 2000 < Re < 4000
- Turbulent for Re > 4000

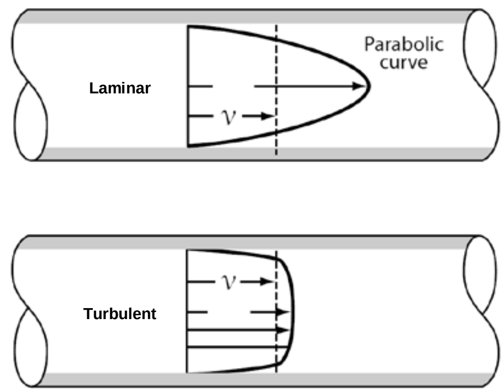



**Figure 20:** Laminar and Turbulent flow profiles

**Hydrodynamic Entry Length**

The hydrodynamic entry length is the distance from the pipe entrance to the point where the friction factor is within 2% of fully developed flow. The hydrodynamic entry length for laminar and turbulent flows are defined by,

$$L_{h,laminar} \cong 0.05ReD$$

$$L_{h,turbulent} \approx 10D$$

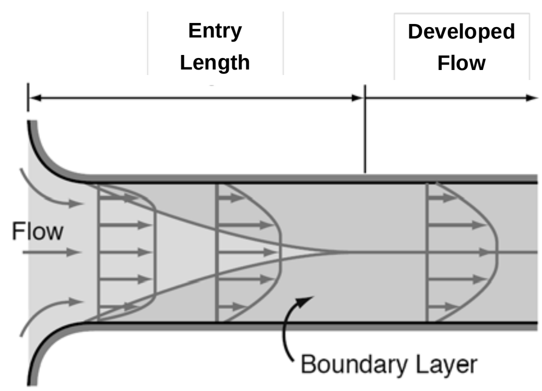



**Figure 21:** Development of flow from entrance to laminar flow conditions

The following factors that need to be taken into account when evaluating pipes as a potential platform for ADVM instruments.

i.) Pipe fittings acting as control features

ii.) Flow disturbance caused by pipe fittings

iii.) Convergence and divergence of different size pipes.

iv.) Jet flow generated by valves

# 4. Site Requirements

Site requirements are fundamental for the effective operation of ADVM instruments and the development of accurate discharge based on measured velocity. The site requirements for ADVM instruments must comply with the same hydraulic requirements when selecting a monitoring site for developing a stage-discharge relationship, designing an artificial gauging weir or where developed pipe flow conditions are present. It can be said that the hydraulic requirements are even more stringent because there exist a direct relationship between the flow conditions at the monitoring site and the measured velocity.

## 4.1 Natural Channels

Site requirements for natural channels are mainly used to define a section of river reach that resembles Steady Uniform flow conditions as much as possible, knowing that these flow conditions seldom or never occur in natural channels and that the actual flow conditions is rather classified under Non-Uniform Unsteady flow conditions. Although flow conditions are an important aspect of site selection, sediment transport, vegetation and flooding is as equal important criterion during the site selection process. These are all factors that can influence the operation of the ADVM and accuracy of velocity and stage measurements.

The following site criteria are listed to assist the user during the site selection process in natural channels taking into account the hydraulic requirements and additional influences such as sediment transport, vegetation and flooding.

i.) Steady Uniform flow conditions

ii.) Sub Critical flow conditions.

iii.) Drawdown zone at section controls should be excluded from the effective measurement volume. The drawdown zone is defined by the distance from the crest of the control to a point upstream.

iv.) Straight length of channel with uniform cross-section and slope (10 times section width).

v.) Uniform velocity distribution over the width of the cross-section.

vi.) Approach velocities with Froude number ≈ 0.5. The flow in the approach channel should be smooth and free of disturbances.

vii.) Unsteady flow and backwater conditions are acceptable within the affective measurement volume, though the user need to determine if a stable and well-defined relationship is viable between the Measured Velocity and the computed Mean Velocity (ONLY relevant to Index Velocity method).

viii.) Flow in the stream should be confined to a single well-defined channel with stable banks.

ix.) Wide flood plains and or secondary channels during flood events should be avoided.

x.) Natural or artificial controls upstream of monitoring site could cause turbulent and unsteady flow conditions and should be located far enough upstream.

xi.) Bends upstream of monitoring site could create skew flows at the point of measurement and should be located far enough upstream.

xii.) Steep slopes upstream of monitoring site could cause turbulent and unsteady flow conditions and should be located far enough upstream.

xiii.) Roughness of the riverbed and banks must be investigated at the site to determine what impact it will have on the velocity distribution

xiv.) Avoid prominent obstructions in a pool that can affect the velocity pattern.

xv.) Discharge sensitivity towards the channel section

xvi.) Aquatic plants can affect the ADVM operation and areas where excessive aquatic plants are present should be avoided.

xvii.) Sediment deposition or scouring can affect the ADVM operations and areas where excessive sediment transport occurs should be avoided.

xviii.) Access to the site during flood events is important.

VITAL

The approaching flow conditions towards the ADVM are of high importance and the reason why most of the site criteria focus on the upstream section of the river reach. By applying these guidelines to the site selection process any upstream influences on the flow pattern will be reduced if it is located at sufficient distance upstream.

ADVICE

The selection of a monitoring site for ADVM's in natural channels can be difficult even for experienced hydrologists. The most important criteria is to ensure that there is sufficient channel length (10 times section width) upstream of the ADVM site that is free of major bends or obstacles that can cause flow disturbance in the channel.

The channel length required upstream of the ADVM monitoring site will ensure that the velocity distribution and flow lines will develop towards uniform flow conditions and this is ideal for ADVM measurements.

## 4.2 Artificial Channels

Site requirements for artificial channels are mainly to define a section of channel reach that resembles steady Uniform flow conditions. In the case of artificial channels, some of the flow parameters such as cross section geometry and slope already conform to Uniform flow requirements in most cases and the only variables that will impact the site selection criteria are the velocity and water depth (wetted area) components.

The site criteria for artificial channels are similar to natural channels with the following additional criteria taken into account the hydraulic requirements and additional influences such as sediment transport and vegetation.

i.) Hydraulic structures upstream could cause turbulent and unsteady flow conditions and should be located far enough upstream.

VITAL

The application of ADVM in artificial channels can be problematic due to the design of the channel network and the hydraulic structures in place that can affect the ADVM operations and accuracy of measurements. Special attention must be given to hydraulic structures that are located upstream of the ADVM and it is highly recommended that ADVM not to be installed at or close to the following hydraulic structures. The hydraulic structures listed are just some examples that can be encountered and are not limited to,

- Sluice Gates
- Channel transitions
- Channel constrictions
- Bends in channel
- Confluences in channel
- Conduit Outlet
- Energy Dissipaters
- Stilling Basin
- Side-overflow weirs
- Siphons
- Gauging Weirs

The site location for ADVM should be at least a minimum of 10 times the section width downstream of the hydraulic structures listed.

ADVICE

The selection of a monitoring site for ADVM's in artificial channels can be difficult in some case due to the limited channel length between hydraulic structures. The ideal flow conditions in artificial channels will exist if the required channel length (10 times section width) is allowed for during the ADVM site selection process.

Hydraulic structures can be used if it is feasible to install the ADVM instrument upstream of the structure. Most hydraulic structures create a damming (backwater) effect on the upstream water level and this reduces the velocity in the channel. The user must take care that the acoustic beam measurements are not affected by any obstacles in the channel.

## 4.3 Bridge Piers

The use of bridge piers for ADVM installations and more specifically the SonTek-SL series is a common method for determining flow mainly of the following reasons,

- Existing monitoring site with data logging capabilities and power supply (if available).
- Bridge pier provide platform for installation and minimal construction is required to perform the installation.
- Bridge pier provide protection against debris during flood events.
- Sediment deposition and or aquatic vegetation are not likely to occur in this region due to the increased velocity.

Site requirements for bridges is mainly to identify flow conditions that resemble Steady Uniform flow conditions as much as possible, knowing that these flow conditions are not defined for bridge hydraulics and that the actual flow conditions is rather classified under Non-Uniform Unsteady flow conditions.

The site criteria for bridges are similar to natural channels with the following exceptions taken into account the hydraulic requirements.

i.) Straight length of channel upstream of the bridge up to 10 times section width with uniform cross-section and slope.

ii.) Bridge pier and embankment alignment with the upstream main channel and or velocity direction should be close to parallel.

**VITAL**

The application of ADVM at bridges will be dependent on the flow conditions as these conditions vary between the bridge design and channel morphology. Special attention must be given to the alignment of the bridge with the river reach and the hydraulic conditions present during different flow ranges with the following to note,

- Bridge pier and or embankment alignment in relation to the main channel direction. Excessive angles can result in skew flow in between the bridge piers increasing the turbulence around the piers.
- The flow regime can change from subcritical to supercritical at the bridge during different flow stages. The change in flow conditions can severely impact the ADVM operation and accuracy of velocity and stage measurements.

Site reconnaissance during different flow stages are crucial in identifying if flow regimes changes during the flow extent occur.

FLAG

Flow turbulence created by the bridge piers or embankment can impact the ADVM measurements. It is recommended that the minimum blanking distance is based on the following formula that incorporates the bridge pier thickness, form factor and distance from upstream face of the bridge pier to the ADVM.

$$d = c \times (b \times x)^{0.5}$$

Supercritical flow conditions or multiple flow regimes within the affective measurement volume of the instrument can impact the ADVM measurements and it is advised that these situations be avoided as far as possible.

The flow conditions directly downstream of bridge piers or embankments are not homogenous. It is not recommended to install an ADVM directly downstream of a bridge, especially if the Beam 1 and Beam 2 are measuring in different flow conditions.

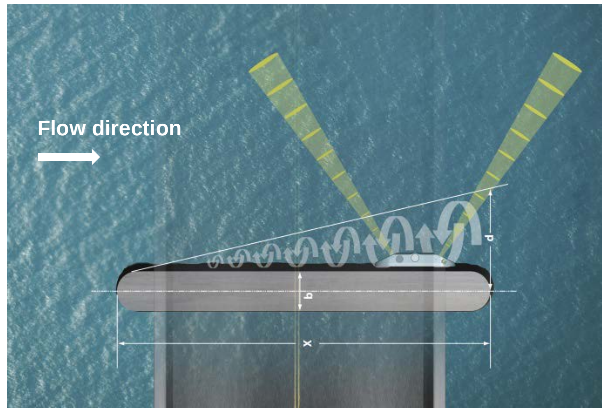



**Figure 22:** Blanking distance requirements

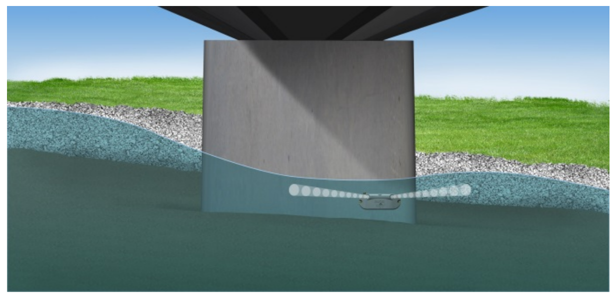


**Figure 23:** SL located in supercritical flow zone

ADVICE

The installation of ADVM instruments and more specifically the Side Looker instruments at bridge piers should be done where the minimum flow disturbance is created by the pier itself. The bridge piers also act as protection during flood events and the position of the instrument and cabling must take this into account.

It is recommended that the instrument be placed in the center of the bridge pier, however flow condition need to be evaluated over range of flows to confirm the final installation.

## 4.4 Culverts

The use of culverts for ADVM installations and more specifically the SonTek-IQ Pipe is a common method for determining flow mainly of the following reasons,

- Culvert provide platform for installation and minimal construction is required to perform the installation.
- Culvert provides protection against debris during flood events.
- Sediment deposition and or aquatic vegetation are not likely to occur in this region due to the

increased velocity. The design of the culvert and maintenance performed downstream will determine the impact of sediment and aquatic vegetation on the instrument operation.

Site requirements for culverts is mainly to define a section of channel reach that resembles steady Uniform flow conditions, knowing that there exists a range of theoretical flow conditions for culverts. In the case of culverts the hydraulic conditions can be extremely variable based on the design of the culvert and the maintenance performed at the culvert and the downstream channel reach.

The site criteria for culverts are similar to natural channels with the following exceptions taken into account the hydraulic requirements.

i.) Straight length of channel upstream of the culvert up to 10 times the section width with uniform cross-section and slope.

ii.) Culvert wall alignment with the upstream main channel and or velocity direction should be close to parallel.

VITAL

The application of ADVM at culverts and more precisely the exact location of the instrument can be problematic due to the possible range of hydraulic conditions within a culvert.

- The flow regime can change from subcritical to supercritical at the inlet or outlet of the culvert during different flow stages. The change in flow conditions can severely impact the ADVM operation and accuracy of velocity and stage measurements
- Non-Uniform gradually varied (backwater) or rapid varied (hydraulic jump) flow conditions can occur within the culvert.
- The flow conditions can change from partially full flow to pipe flow during a single event which will be difficult to account for if the instrument selection was based on open channel flow conditions.

Site reconnaissance during different flow stages are crucial in identifying if flow conditions changes during the flow extent.

FLAG

The ADVM measurements can be affected if the instrument is located in the critical flow zone at the inlet or outlet of the culvert and it is advised that these situations be avoided as far as possible.

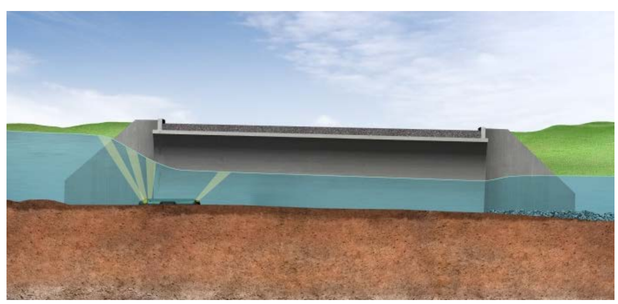


**Figure 24:** IQ located in critical flow zone

A D V I C E

Flow conditions at culverts can vary and it is recommended that site reconnaissance is performed during different flows to determine the monitoring location. The site characteristics can reveal sufficient information even during dry conditions to determine the instrument position and the following aspects can be used in the decision making process,

- Sediment deposition in the culvert
- Clean culvert floor can indicate zones of high velocity
- Water lines or debris on the side walls can indicate the type of flow conditions present in the culvert
- The angle of the channel upstream of the culvert will influence the velocity distribution within the culvert
- Vegetation and sediment downstream of the culvert can create damming effect (backwater) and thus reducing the velocity

## 4.5 Pipes

### 4.5.1. Partial Full Flow

The use of SonTek-IQ Pipe in storm water and raw water applications are industry standard for accurately determining flow mainly of the following reasons,

- Measure the velocity profile across the entire water column.
- Measure velocity and depth with independent sensors.
- Operate in high sediment concentration levels.
- Ability to measure partial and full flow condition with single instrument.
- Theoretical flow calculation produces accurate results.

Site requirements for partially full pipes are mainly to define pipe section that resembles Steady Uniform flow conditions. In the case of partially full pipes, some of the flow parameters such as cross section geometry and slope already conform to uniform flow requirements in most cases and the only variables that will impact the site selection criteria are the velocity and water depth (wetted area) components.

The site criteria for partially full pipes are similar to natural channels with the following additional criteria taken into account the hydraulic requirements.

i.) Hydraulic structures upstream could cause turbulent and unsteady flow conditions and should be located far enough upstream.

ii.) Hydraulic design of the manhole.

iii.) Access to instrument from existing manholes.

V I T A L

The application of ADVM in partial full pipes will be dependent on access to pipes from existing manholes and the hydraulic conditions within the pipe can be problematic due to the hydraulic structures.

- The flow regime can change from subcritical to supercritical (supercritical to subcritical) at the inlet or outlet of the manhole. The change in flow conditions can severely impact the ADVM operation and accuracy of velocity and stage measurements.
- The effect of the water pool depth and air entrainment in the manhole.
- Flow chocking as a result of the inlet and outlet design of the manhole.
- Non-Uniform gradually varied (backwater) or rapid varied (hydraulic jump) flow conditions can occur within the pipe.
- Sediment accumulation at hydraulic structures that can severely impact the ADVM operation and accuracy of velocity and stage measurements.

Site reconnaissance during different flow stages are crucial in identifying if flow conditions changes during the flow extent.

### 4.5.2. Pressure Flow

The use of SonTek-IQ Pipe in pipes under pressure flow conditions are industry standard for accurately determining flow mainly of the following reasons,

- Measure the velocity profile across the entire water column.
- Measure velocity and depth with independent sensors.
- Theoretical flow calculation produces accurate results.
- Suitable for range of pipe diameters.

Site requirements for pressure flow pipes are mainly to define pipe section that resembles Laminar flow conditions as much as possible, knowing that these flow conditions seldom or never occur in pipes and that the actual flow conditions is rather classified under Turbulent flows.

The site criteria for pressure flow pipes are similar to natural channels with the following additional criteria taken into account the hydraulic requirements.

i.) Minimum of 10 times the diameter downstream of pipe fittings

ii.) Position of instrument should be 20 times the diameter downstream of valves.

iii.) The maximum hydraulic pressure must not exceed the instrument pressure sensor range of 30m (98ft; 42psi).

V I T A L

The application of ADVM in pipes can be problematic due to the design of the pipe network and pipe fittings that can affect the ADVM operations and accuracy of measurements. Special attention must be given to pipe fittings that are located upstream of the ADVM and it is highly recommended that ADVM not to be installed at or close to the following pipe fittings. The pipe fittings listed are just some examples that can be encountered and are not limited to,

- Bends
- Elbows
- Pipe Tees
- Pipe Reducers
- Pipe Restrictions
- Expansion Joints
- Outlets
- Meters
- Valves

F L A G

- The site location for ADVM's should be at least a minimum of 10 times the pipe diameter downstream of pipe fittings listed.
- In the case of valves and pipe restrictions that can generate jet flow, the distance downstream should be at least 20 times the pipe diameter.
- The maximum hydraulic pressure must not exceed the instrument pressure sensor range of 30m (98ft; 42psi).

# 5. Site Related Cases

## 5.1 SonTek-SL Series

### Boundary Effects

Boundary effects can bias the velocity measurements low and the user needs to make sure during the site selection and instrument installation process that the ADVM measurement is not affected by any boundary influences. The boundaries that can impact on ADVM measurements are, channel bed, opposite channel bank, water surface and obstructions in the channel

**Figure 25:** SL installation

The boundary effects can be prevented by applying some practical applications during instrument installation,

- Aspect ratio (range / distance) is in the order of 15–20 and is dependent on site conditions.
- Cell end is 10% of channel width from opposite bank

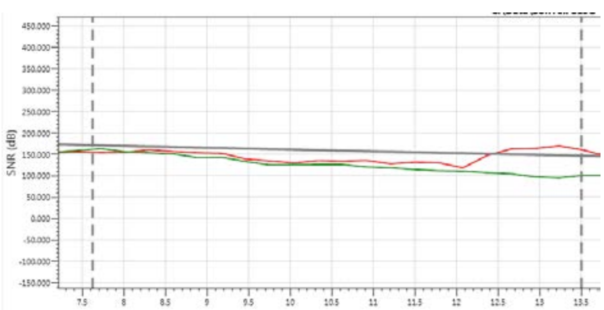



**Figure 26:** SNR Diagnostic View Plot

The SNR data indicate that the water surface or channel bed is affecting the measurement at about 12m from the instrument. In this case the instrument can be raised or lowered depending on the type of boundary that affects the measurement. The following criteria can be used to define the instrument position,

- Aspect ratio
- Extent of variation in water level

Bathometry survey was performed with HydroSurveyor across the effective measurement volume to determine if there were any obstructions in the channel or if the cross section geometry as such could influence the measurements. The survey did highlight some anomalies that can impact the velocity measurements, however the operational water level limited the adjustment of the instrument and as a result the profiling range will be limited to 12m.

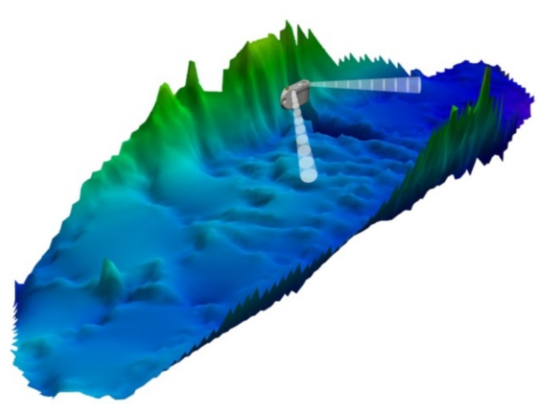


**Figure 27:** Bathymetric survey of channel

## Velocity Distribution

The velocity distribution can vary throughout the discharge extent and the site reconnaissance need to incorporate the following criteria during the process,

- Velocity distribution throughout discharge extent
- Stage Discharge sensitivity of section

The plots show the magnitude and direction of each individual cell velocity during high and low flow conditions. The measured cell velocities during medium to high flow conditions shows that the velocity distribution across the section is well distributed and uniform.

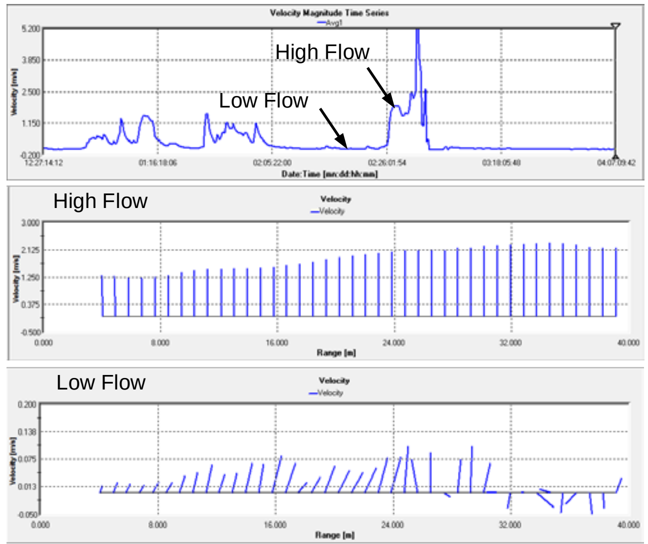



**Figure 28:** Velocity Magnitude plot

The low flow conditions are the exact opposite with skew flow occurring in most of the section and backflow present on the left bank. The velocity distribution during low flow conditions is a result of a combination of the following site related aspects,

- Wide measurement section
- Deep upstream pool
- Stage discharge relationship is not sensitive.

## 5.2 SonTek-IQ Plus

### Beam Burial

Beam burials are more applicable to bottom mounted ADVM's, more specifically the IQ series. Beam burials occur when one or all beams are buried under sediment and the instrument is unable to operate sufficiently under these conditions.

The SNR plot is a good indicator to verify if beam burial has occurred. If there is a consistent downward trend in the SNR plot towards zero for one or all beams, it indicates that beam burial has occurred.

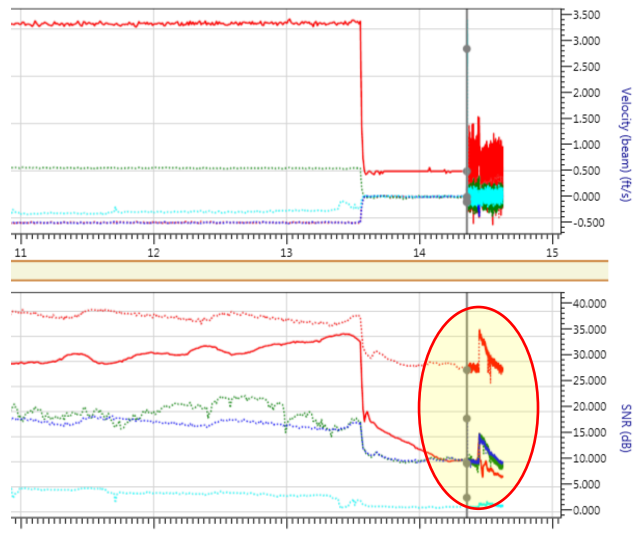



**Figure 29:** SNR Plots Indication Beam Burial

### Instrument Alignment

The cross section geometry and the instrument position in relation to the cross section need to be accurately determined. The exact measurements as surveyed must be entered in the IQ software in the "Channel Shape" section.

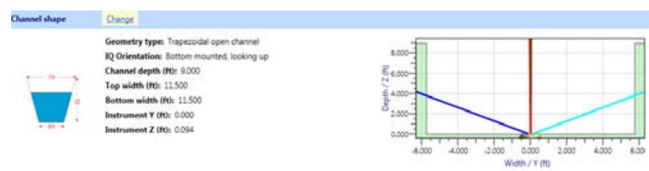


**Figure 30:** IQ Channel Shape setup page

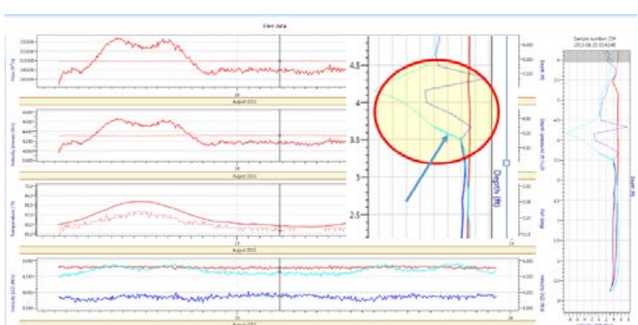


**Figure 31:** Velocity Profile of Skew Beams

The velocity profile of the skew beams in this scenario shows that there is reduction in velocity at the last measured cell at each of the skew beams. The beams are hitting the walls of the channel on both banks and as a result the velocity is biased low.

### Non-uniform Flow Conditions (Integrated Method)

The integrated velocity method is based on theoretical flow principles with the assumption that the flow conditions are uniform and that the instrument is positioned in the zone where maximum velocity occurs.

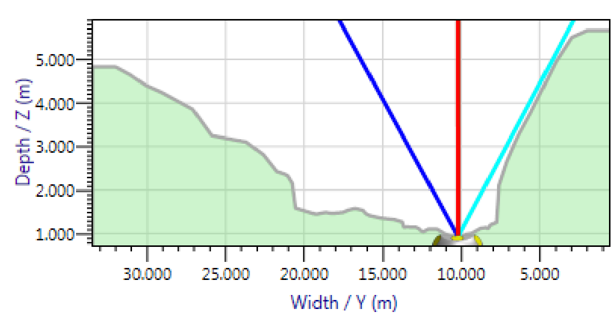



**Figure 32:** IQ Position relation to channel

The scenario shows the instrument is situated close to the right bank with the beam starting to intercept with the cross section above 2m. The further the site deviates from the theoretical flow conditions the larger the error will be on the mean velocity and discharge calculations. It is also important to note that side lobe interference will bias the velocity low as a result of the beam intercepting the right bank.

## 5.3 SonTek-IQ Pipe

### Jet Flow

Jet flow occurs in pipes when the conduit flow area is reduced in combination with hydraulic pressure available. The extent of jet flow is dependent on the ratio of reduced flow area and hydraulic pressure. Jet flow can be generated by the following pipe fittings,

- Valves
- Pipe constrictions

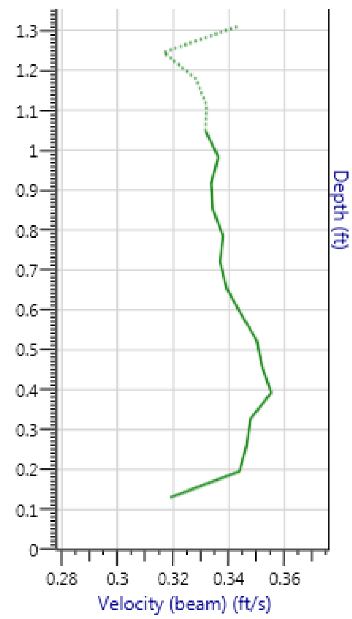



**Figure 33:** Velocity distribution at 25% valve opening

The instrument is positioned in a pipe network downstream of balancing tank at a distance of 15 x diameter. The graphical illustrations show the velocity distribution in the pipe for 25% and 75% valve opening. The 25% valve opening clearly shows that the maximum velocity occurs about $^1/_3$ from the bottom of the pipe. The 75% valve opening shows a better velocity distribution and start to resemble the theoretical velocity profile for turbulent flow conditions in pipes.

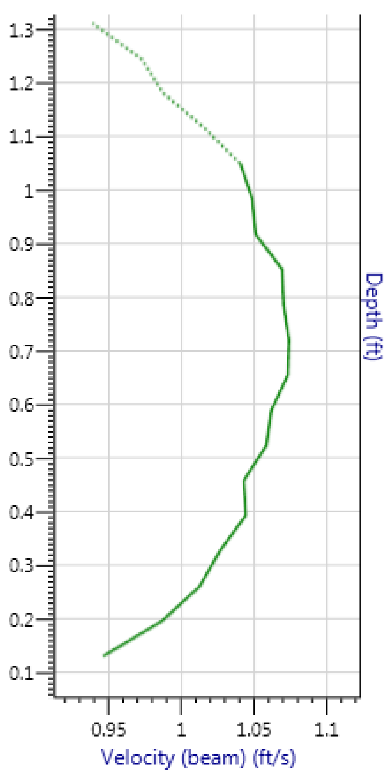



**Figure 34:** Velocity distribution at 75% valve opening

Jet flow conditions can impact the ADVM operation and accuracy of measurements and it is recommended that the installation of ADVM's from valves should be at least 20 x diameter of the pipe downstream.

# 6. Site Reconnaissance

The site selection process should be based on set hydraulic criteria and site reconnaissance during different flow ranges, which can be performed by making use of trial installations using an ADVM, discrete discharge measurements with Acoustic Doppler Current Profiler (ADCP), performing bathometric survey with ADCP mapping both elevation and velocity contour information, continuous stage measurements or combination of the above. It is important to note that the site selection cannot be based only upon hydraulic requirements as stipulated in this technical report and that site reconnaissance forms a key part of the process.

Site reconnaissance for potential ADVM monitoring sites can be performed using a number of methods and the extent of the reconnaissance work is dependent on the availability of flow throughout the discharge extent and the monitoring objectives of the site. The following methods can be utilized to perform the site reconnaissance at an ADVM monitoring site,

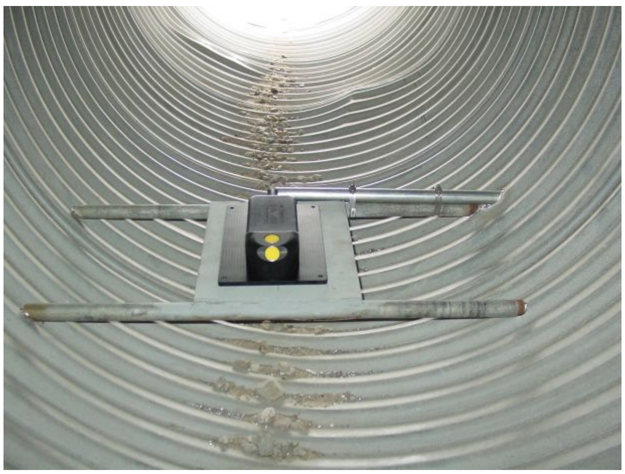
<table>
<tr><th>Reconnaissance Method</th><th>Information Source</th><th>Application</th></tr>
<tr><td rowspan="3">Hydrological Data</td><td>Determine the flow extent</td><td>• The instrument location in relation to historic water levels.<br>• Measurement range within the instrument specifications</td></tr>
<tr><td>Recurrence interval of events</td><td>• The instrument location in relation to the mean velocity will be impacted by the recurrence interval of flow extent.</td></tr>
<tr><td>New monitoring site, refer to other sites in catchment if applicable</td><td>• If hydrological data are not available at the site, evaluate other sites in the catchment and determine if the data sets are applicable.</td></tr>
<tr><td rowspan="2">Trial ADVM Installation</td><td>Determine velocity distribution throughout the discharge extent</td><td>• Velocity distribution and approach angle can vary throughout the flow extent and it is important to identify any changes that might occur.</td></tr>
<tr><td>Identify any boundary effects</td><td>• Determine the instrument location in relation to the river bed using the aspect ratio as a guide.<br>• Determine the end cell location in relation to opposite bank using the 10% of total width as a guide.<br>• SNR Plot</td></tr>
</table>

| Reconnaissance Method | Information Source | Application |
|---|---|---|
| | Identify possible objects that can interfere with measurements | • SNR Plot |
| | Location of the instrument in relation, | • Mean velocity<br>• Cable maximum length |
| | Identify installation method, construction requirements and level of protection for a permanent installation | • Foundation and slope stability<br>• Flood (debris)<br>• Environmental conditions (sun, ice, etc.)<br>• Vandalism<br>• Cable installation |
| ADCP | Discharge Measurement | • Develop stage discharge curve<br>• Determine discharge sensitivity |
| Dual Stage Measurement | Stage measurement | • Determine the flow extent |
| | Stage measurement upstream and downstream of proposed site | • Identify change in surface water slope<br>• Identify variation in surface water and bed slope |
| Surveys | Cross Section | • The instrument location in relation to the river bed using the aspect ratio as a guide.<br>• The instrument location in relation to the deepest portion or center of the section.<br>• The end cell location in relation to opposite bank using the 10% of total width as a guide. |
| | Bathometry (HydroSurveyor) | • Influences on ADVM measurement across the effective measurement volume.<br>• Velocity distribution and flow angle within the channel reach. |
| Photographs | Flow Conditions | • Approach flow conditions.<br>• Flow conditions at the monitoring site |
| | Cross Section | • Possible vegetation impacts on ADVM.<br>• Geometry of cross section and possible impacts on ADVM. |

# 7. ADVM Mountings

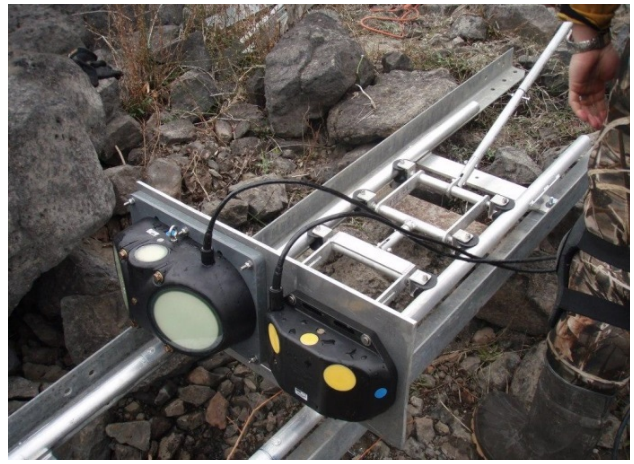
The ADVM mounting types shown in this section is based on collection of user application of SonTek ADVM instruments over the years and the examples supplied should serve as a guide for applying instrumentation in various channel configurations in both natural and artificial channels.

## 7.1. Pipes \ Culverts



# 7.2. Artificial Channels

## 7.3. Natural Channels



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