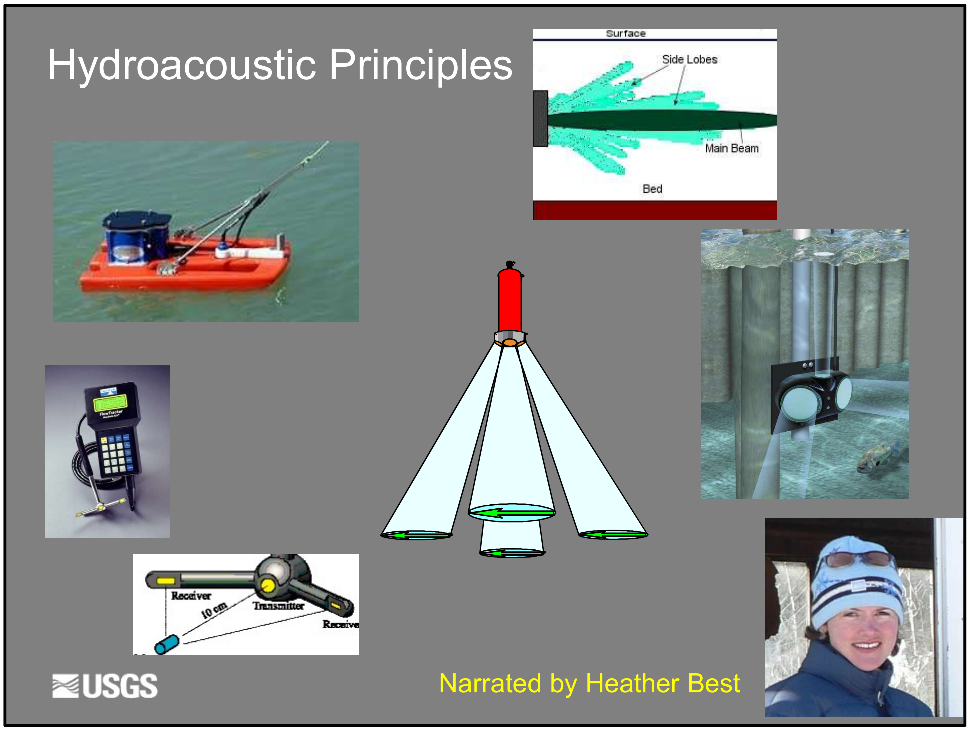
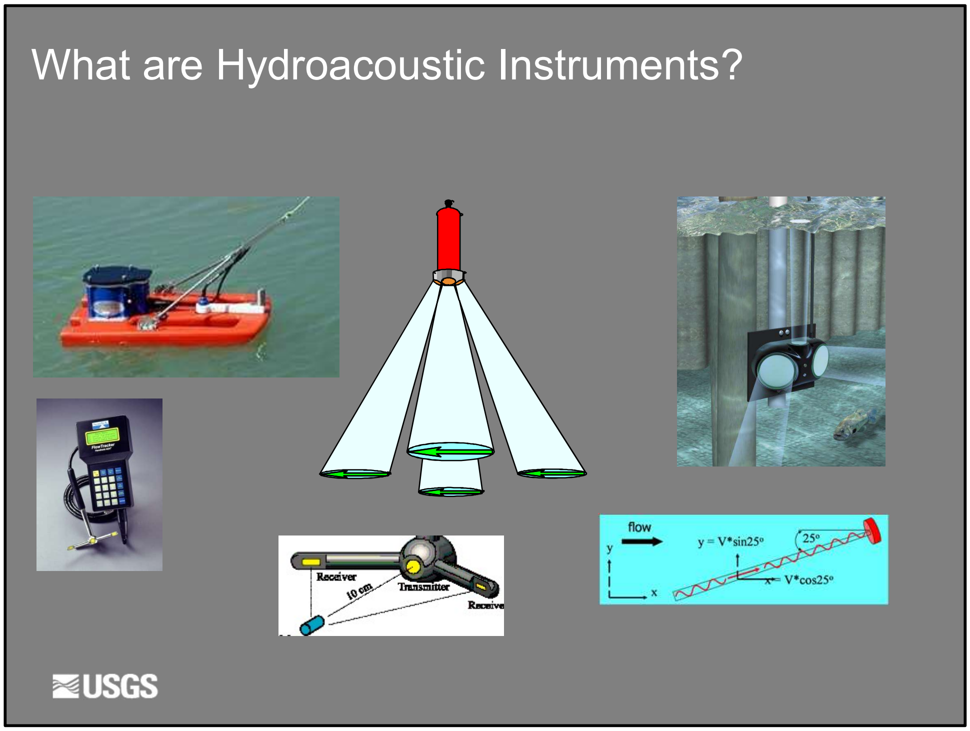
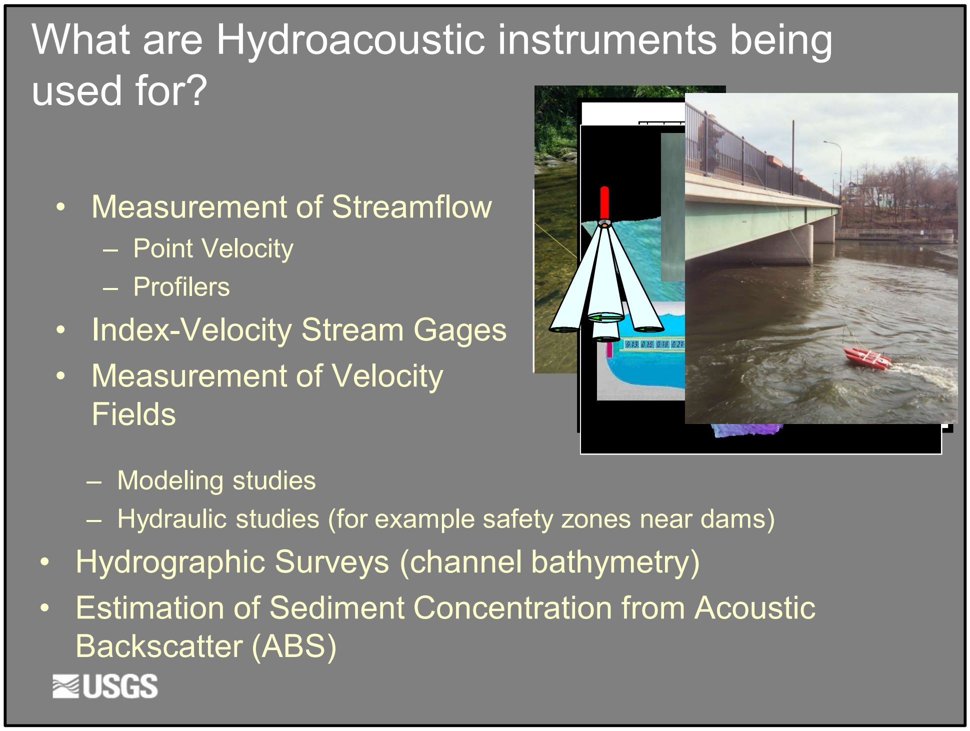


This module is called hydroacoustic principles and is intended to provide the student with an understanding of:

- What a hydroacoustic instrument is
- What they are being used for
- Basics of how a hydroacoustic instrument works and an
- Introduction to instrument applications

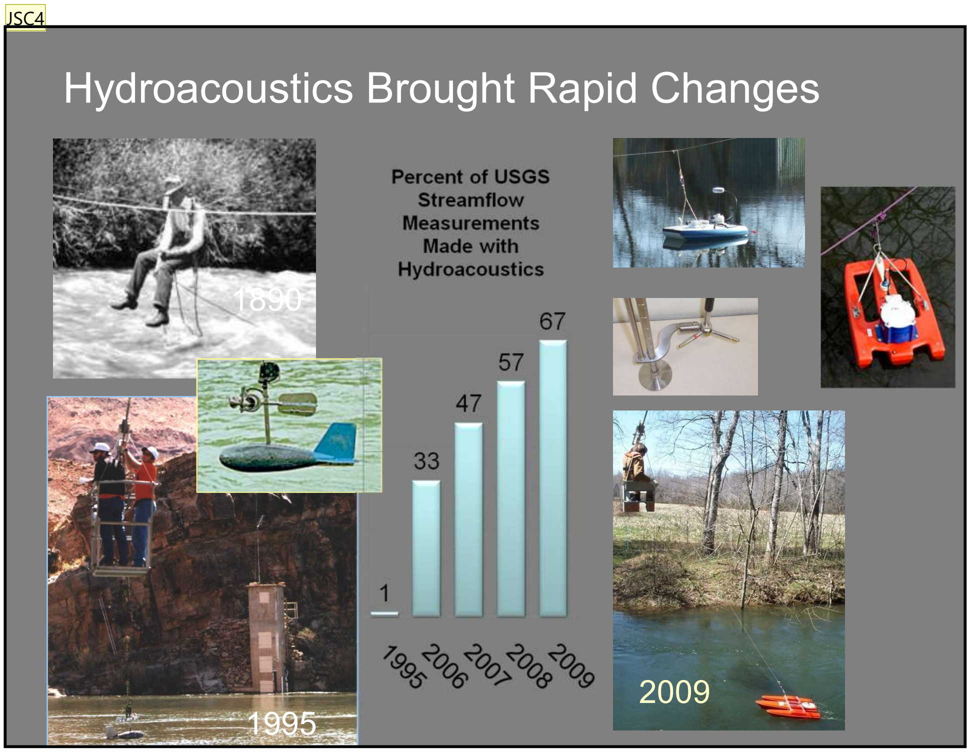


Hydroacoustics is a general term for the study and application of sound in water. Hydroacoustic instruments transmit sound into the water and use the returning sound to measure parameters such as, water velocity, river depth, and boat speed.



Hydroacoustic instruments are used in variety of applications including:

- Measurement of Streamflow
    - Some measure point velocities at multiple locations across the channel
    - Others measure entire profiles from a moving boat
- They can be permanently mounted in the stream at Index-velocity stream gages to measure velocities that are then used to compute real-time discharge at sites without a good stage discharge relationship.
- They can be used in the Measurement of Velocity Fields such as,
    - Modeling studies and
    - Hydraulic studies, for example safety zones near dams
- In hydrographic surveys for measuring channel bathymetry.
- Estimation of Sediment Concentration

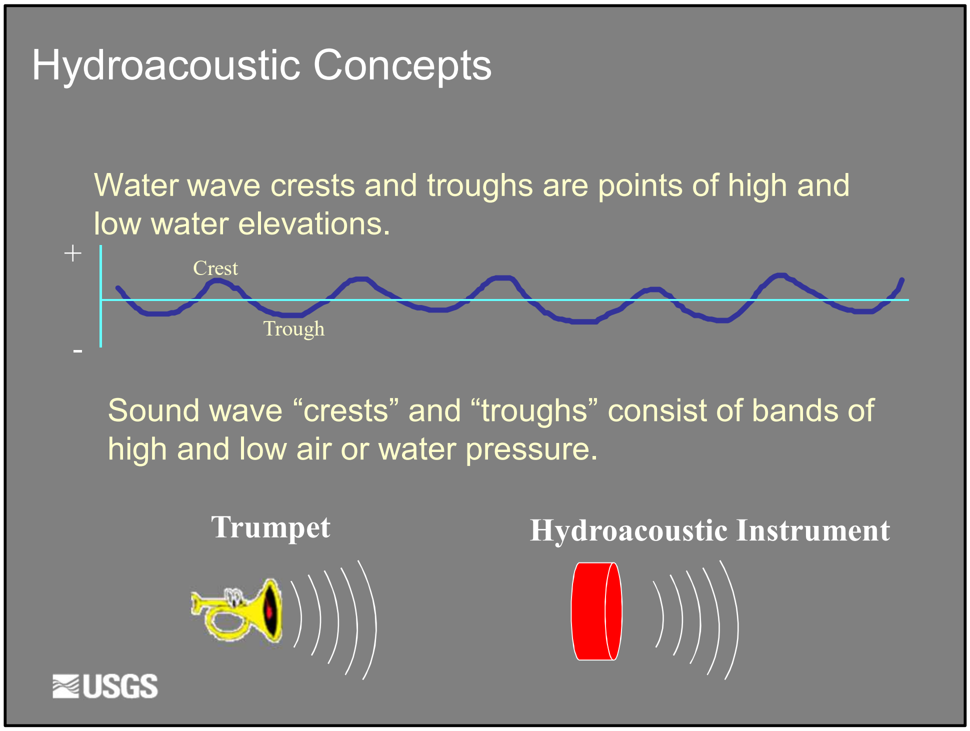


For well over a hundred years, the equipment used to measure streamflow changed very little. However, technological advancements in the past decade have resulted in many new instruments that use hydroacoustics to measure streamflow. In 1995 less that 1 percent of the streamflow measurements made in the USGS used hydroacoustic equipment. By 2008 the majority of streamflow measurements were made instruments using hydroacoustics technologies. (Need reference)

Slide 4

JSC4 This would be a good spot for that slide that Kevin has displaying the number of HA instruments in the USGS and the number of QMMTS made with HA.

jconaway, 11/27/2009



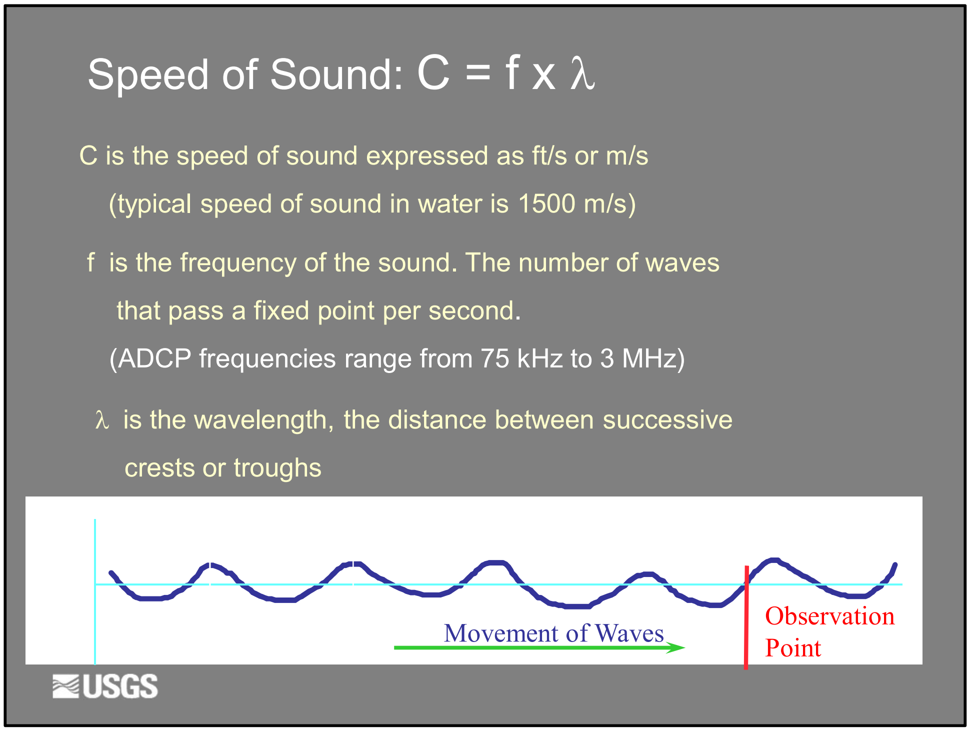
Now we will discuss the basic concepts of how hydroacoustic instruments work.

You are probably familiar with water waves. Water waves have crests and troughs which are high and low water elevations.

Sound waves are similar but their crests and troughs are areas of high and low pressure in whatever medium the sound is traveling through, which in the cause of hydroacoustics is the water in the stream.

The frequency of the sound may be audible to the human ear such as the sound of a trumpet.

Or it may be a frequency that we cannot hear such as the sound transmitted from an hydroacoustic instrument.



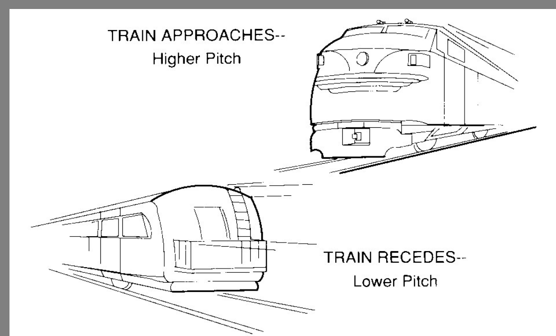
The speed of sound in water is equal to the frequency of the sound multiplied by the wave length. The common variable for the speed of sound is “C”. The typical speed of sound in water is about 1500 m/s. “f” is the frequency of the sound. It is defined as the number of waves that pass a fixed point per second. Low pitch sounds such as from a bass drum have a low frequency while sounds from a squeaky hinge likely have a high frequencies. The frequency range of typical hydroacoustic instruments are from 75 kHz to 5 MHz.

Lambda is the wavelength of the sound wave. It is the distance between successive crests or troughs.

Therefore the speed of sound is defined by the frequency of the sound and its wavelength. The speed of sound is fixed for a given set of water conditions (temperature and salinity) and the frequency of the ADCP doesn’t change so as the water conditions vary the wavelength of the sound wave changes.

How does an hydroacoustic instrument work?

- ***Uses Doppler shift to measure water velocity***
- ***The Doppler effect is the change in a sound's*** **observed** ***pitch (frequency) caused by the*** **relative** ***velocities of the sound source and receiver.***



Visit https://imagine.gsfc.nasa.gov/features/yba/M31_velocity/
for a more detailed discussion

USGS

Hydroacoustic instruments can use the change in frequency, called Doppler shift, to determine speed.

I am sure you have heard the pitch of a siren on a police car, ambulance, fire truck or horn on a train sound higher in pitch as it approached you and lower in pitch as it drove past and away from you.

This change in sound caused by the vehicle coming towards you and then away from you is the Doppler shift.

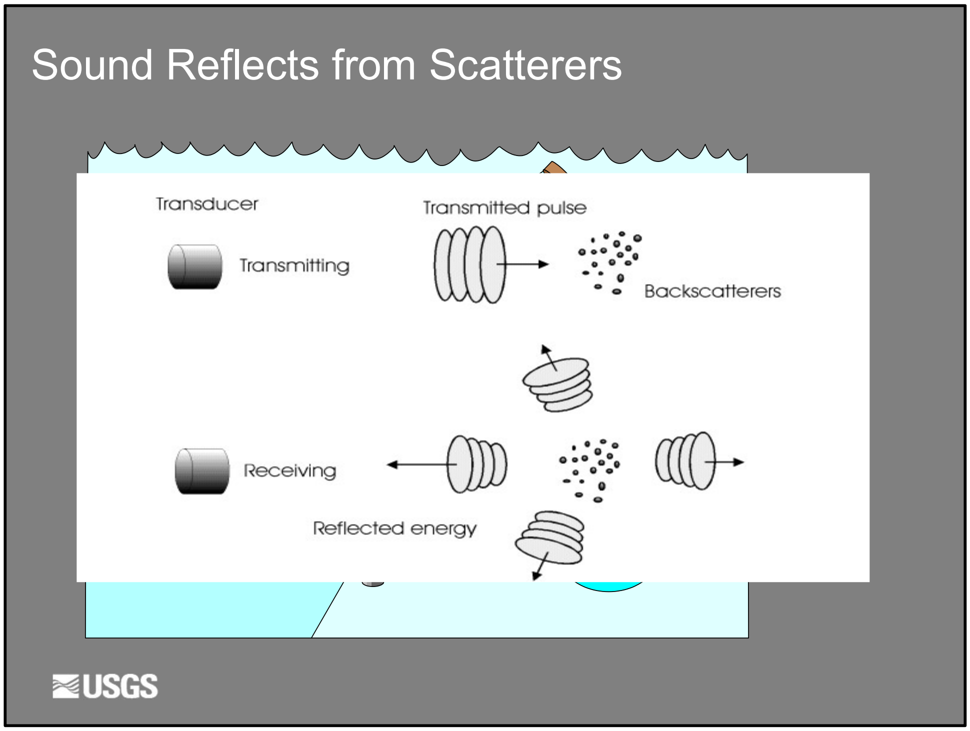
As a sound source travels towards you, the sound waves are compressed and the sound you hear has a higher pitch or frequency than the sound actually being transmitted.

Conversely, as a sound source travels away from you the sound waves are stretched and the sound you hear has a lower pitch or frequency than the sound actually being transmitted. By measuring the change in sound frequency and knowing the frequency of the sound being transmitted the speed of the sound source can be computed.

Note: either the source of the sound or the sink (listener) can move or both.

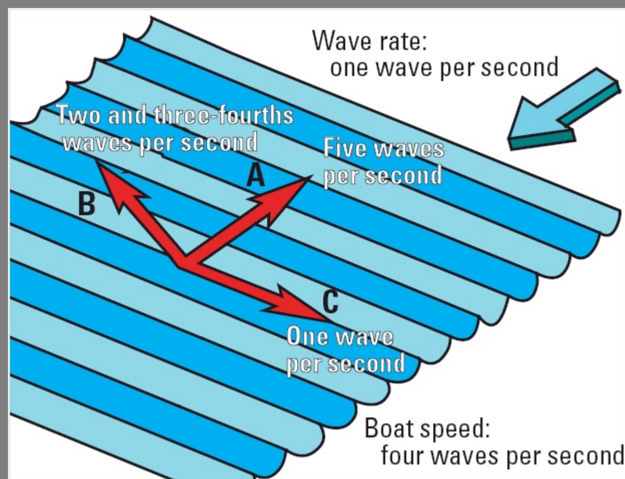
GOOD link to more info on the Doppler shift:

https://imagine.gsfc.nasa.gov/features/yba/M31_velocity/



Actually hydroacoustics instruments do not measure the velocity of the water because pure water is acoustically transparent. It actually measures the velocity and direction of small particles and organisms in the water column. The instrument sends out a burst of acoustic energy and then listens for the backscattered energy from particles in the water column. By **comparing** the frequency of the output energy **relative to** the frequency of the returned energy the instrument uses the Doppler shift principle to compute the speed of the water column.

Doppler Shift Measures Relative Velocity



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The doppler shift measures a relative velocity.

Let’s look at what happens with an observer on a boat moving in various directions as noted by the arrows A, B and C, while the waves are moving at a constant rate of one wave per second and the boat is moving at a speed equal to 4 waves per second.

When the boat is moving along path A, where the boat is headed into the waves, the person on the boat would observe 5 waves passing each second. A result of the wave rate in addition to the boat speed.

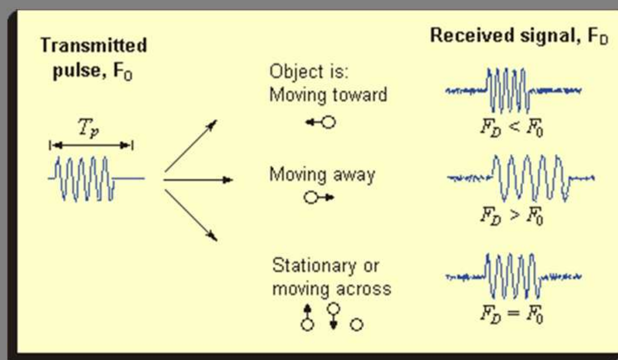
If the boat is headed along path B, only the portion of the boats motion in the direction of the waves would be added to the observed wave rate. In this case resulting in a observed rate of two and ¾ waves per second

If the boat were headed along path C, which is perpendicular to the wave direction, the person on the boat would only observe one wave per second.

These changes in number of observed waves are analogous to changes in the **acoustic** wave length, or frequency shift.

Direction

Direction of the scatterer motion is also determined from the frequency shift:



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The frequency shift tells us not only the speed but the direction of motion of the particles in the water column, referred to as scatterers. As mentioned in the train example of a Doppler shift, a “stretched” wave tells us motion is away from the transducer. A “compressed” wave tells us the scatterers are moving towards the transducer. The wave doesn’t change if there is no motion relative to the transducer.

The Doppler Equation

$$f_D = f_S * V/C$$

f_D = Doppler Shifted Frequency

f_S = Source Frequency (frequency of ADCP)

V = Velocity of scatterers in water

C = Speed of Sound (dependent on water char.)

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The equation for computing the velocity of the sound source from the Doppler shifted sound frequency is shown here.

We know source frequency and Speed of sound (based on our instrument and the salinity and temperature of the water)

The instrument can measure the doppler shifted frequency

Therefore, we can compute Velocity

Importance of Speed of sound (C)

$$V = (f_D / 2f_S *)C$$

<u>Important</u>

Speed of sound (C) must be computed accurately by the instrument.

- A temperature error of 2° Celsius (5° F) or salinity error of 5 ppt will result in a 1% velocity error
- The instrument must have an accurate temperature sensor and must be configured for the correct salinity

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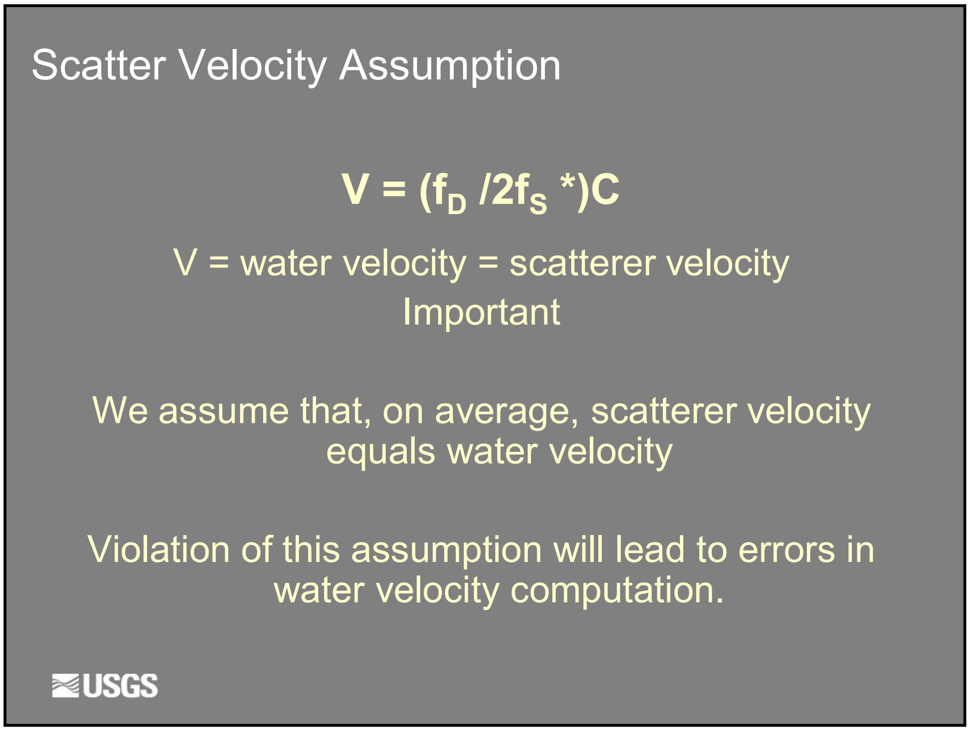
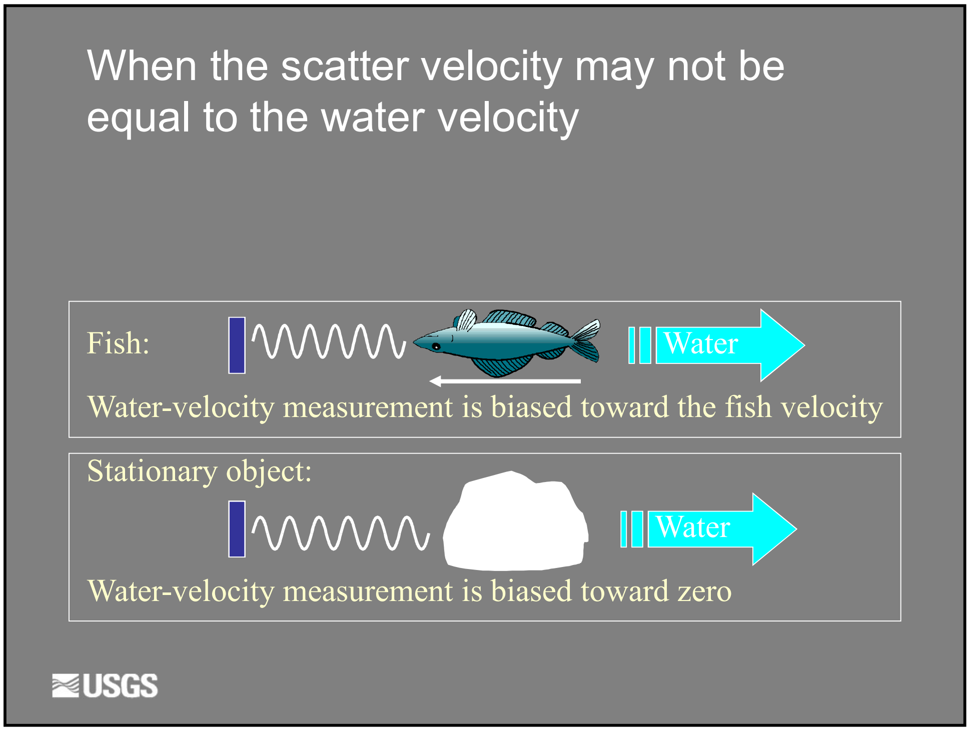
Speed of sound must be computed accurately to get the velocity measurement right. In the equation for speed of sound underwater, temperature is the largest factor affecting C. Therefore temperature must be accurately measured by the instrument at the transducer head to accurately compute C. Salinity is another Important factor.

A temperature error of 2 degrees celsius or a salinity error of 5 ppt would result in approximately a 1 percent error in measured velocity.



As we have already mentioned, hydroacoustics instruments do not measure the velocity of the water because pure water is acoustically transparent, but measures the velocity and direction of small particles and organisms, called scatterers, in the water column. We assume water velocity = scatterer velocity. If this assumption does not hold we introduce errors into our water velocity computations.



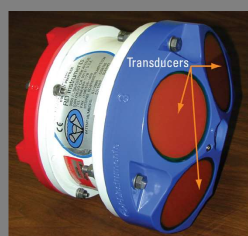
Examples where the scatterer velocity is not equal to water velocity. In case 1 the fish is the scatterer– the velocity of the fish is measured, and the fish may be moving at a completely different speed and direction than the water. A large stationary object such as a rock will bias velocities toward the speed of the object which is zero.

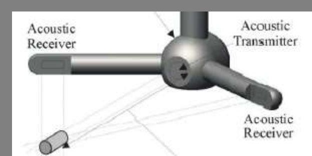
Transducers transmit and receive the sound

Electro-mechanical elements that deform or vibrate, producing sound waves that can listen to returning sound waves turning them back into electrical signals

Consist of a ceramic element protected with a urethane coating

Most instruments are monostatic, meaning the transducer both transmits *and* receive sound waves. When Separate transducers are used for transmitting and receiving – called bistatic





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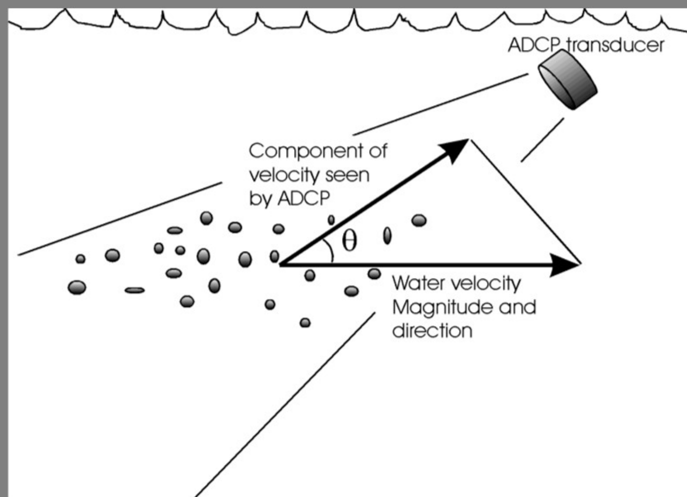
Hydroacoustics instruments use transducers to transmit and receive sound waves. A transducer consists of a ceramic element that is caused to deform or vibrate by application of an electrical current. The ceramic element is usually protected by urethane. The transducers used in ADVM's and ADCPs are monostatic, meaning they both transmit and receive sound waves. The other type of transducer is bistatic, these types transmit only or receive only – they are used in ADV's, for example.

Measures Velocity Parallel to Beam



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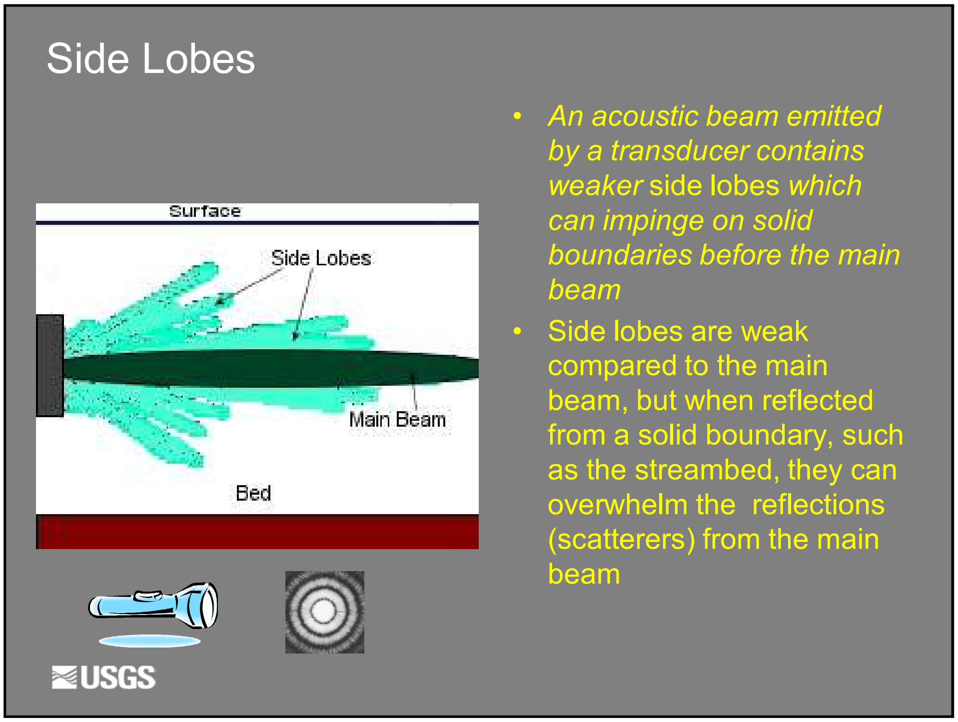
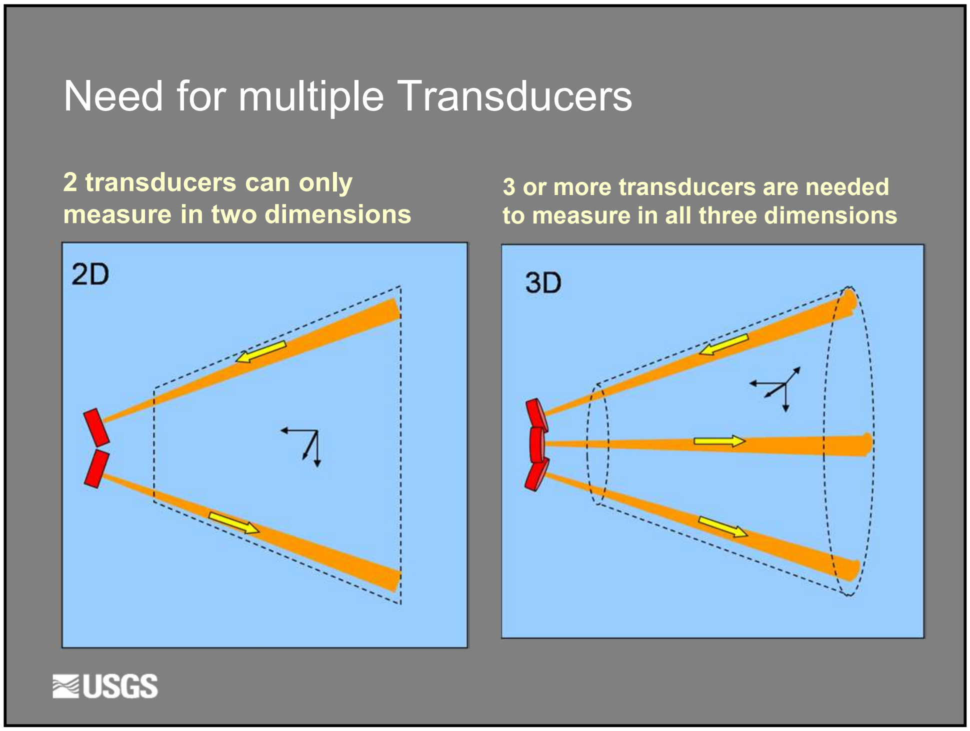
Hydroacoustic instruments only measure velocity of the scatterers parallel to the beam. This is also called a radial velocity.

If the scatterers in this diagram are moving from left to right as indicated by the arrow, only the component of the vector parallel to the acoustic beam would be measured.

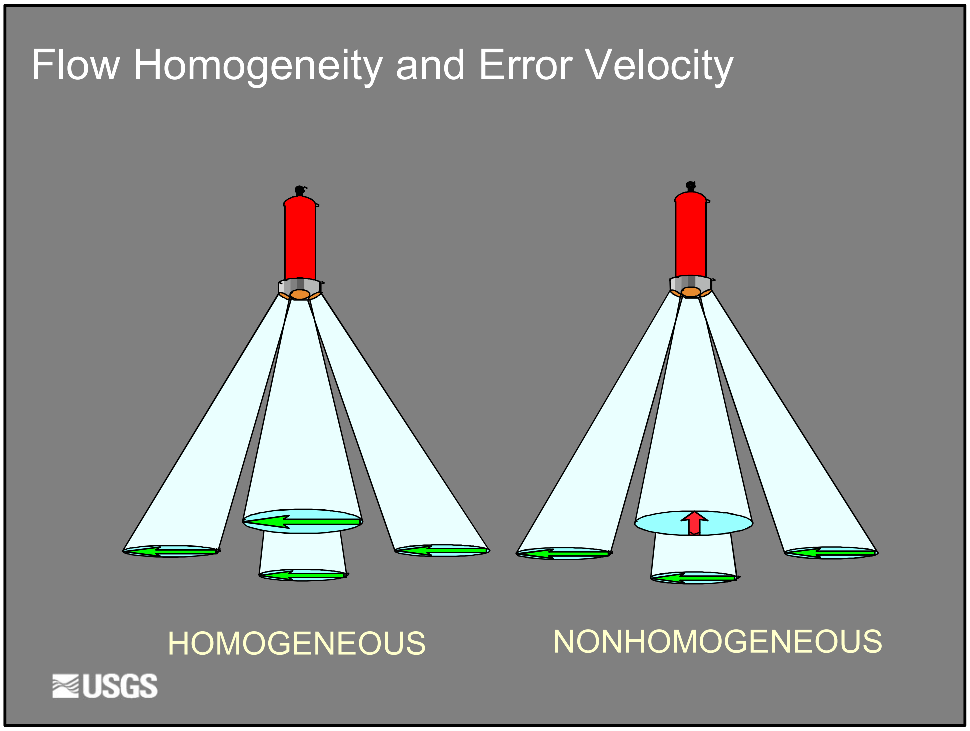
What velocity would we measure if we pointed a transducer straight down in the water column? Only the vertical velocity, because the horizontal velocity would be perpendicular to the beam. This is why the ADCP has multiple transducers that are tilted in different directions.



When acoustic transducers produce sound, most of the energy is transmitted in the main beam. Unfortunately there are also side lobes containing less energy that propagate from the transducer as well. These side lobes are not a problem in most of the water column because they are of such low energy. However, when the side lobe strikes the streambed, the streambed is a good reflector of this acoustic energy and much of the energy is reflect back to the transducer. Because of the slant of the beams the acoustic energy in the main beam is reflecting off of scatters in the water column near the bed at the same time that the side lobe is reflecting from the streambed. The energy in the main beam reflected from these scatters in the water column is relative low compared to the energy sent out from the transducer and the energy in the side lobe returned from the streambed is sufficient to contaminate the energy from the main beam near the bed. This affect is similar to light that leaks out around the main beam of a flashlight that can be seen when pointing it at a wall.



ADCP's can only measure the velocity components parallel to the beams present in the ADCP. However, if we assume that the velocity is the same in each beam then we can use trigonometric relations to resolve the beam velocities into something more useful to use, velocity in the horizontal (x and y) and vertical (z) directions. Therefore, beam velocities from three beams are necessary. ADCPs with 3 beams can measure the x, y, and z components of the velocity field.



Since the doppler shift is directional and each beam is only measuring a small component of velocity parallel to the beams, when the radial velocities are resolved into horizontal and vertical components, the assumption is made that all beams are measuring a homogeneous volume of water (seeing the same velocity magnitude and direction). Remember the instrument is looking at the individual beams not the entire volume of water contained inside the boundary of the beams.

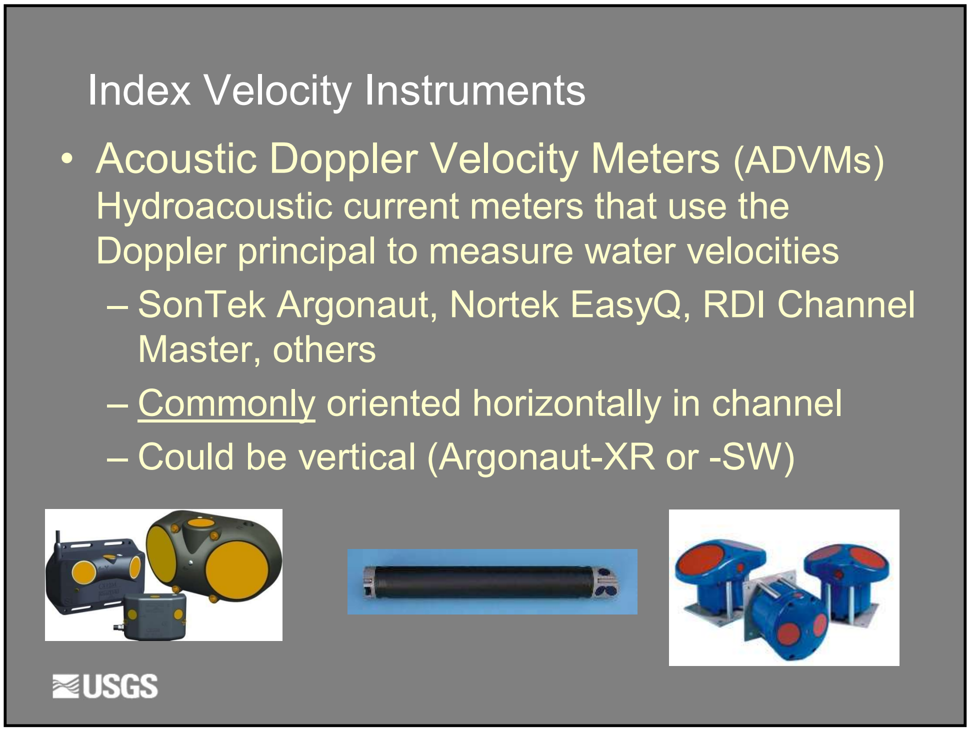
What are the potential sources of error?

A vortex or eddy in one beam

Random errors

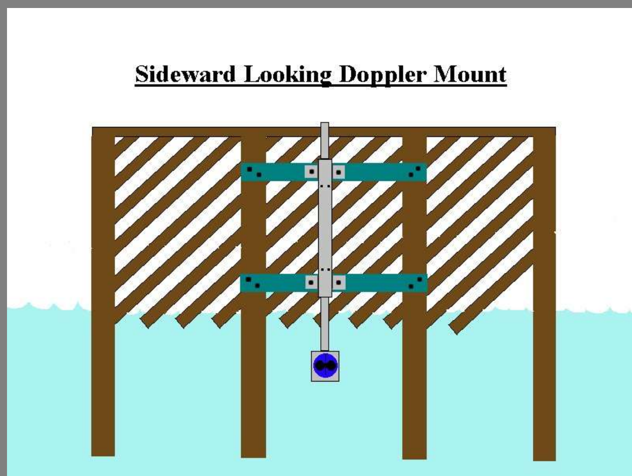
Some instruments have an additional fourth beam. The fourth beam is not required to compute the horizontal and vertical velocities but it does allow the computation of what has been called the error velocity, which is the difference in vertical velocity for the beam pairs.

The error velocity gives a an indication of flow homogeneity and is an indicator of the validity of the assumptions used to compute the horizontal and vertical velocity components.



Index velocity instruments are typically called Acoustic Doppler Velocity Meteres or ADVM's and are current meters mounted at gaging stations that use the Doppler principal to measure water velocities. Examples include the SonTek Argonaut and NorTek EasyQ. ADVM's are usually oriented so that they "look" out across the channel. But some, such as the Argonaut-XR or SW can be pointed to measure velocity vertically.

Typical index velocity deployment of an ADVM



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Here is a typical deployment of an ADVM. In this case it is mounted looking out across the channel to measure a stream velocity that can be indexed to the mean channel velocity. This index velocity is then multiplied by a reference area to compute discharge. ADVMs are typically used a sites that do not have a direct relation between stage and discharge.

JSC3

What does an ADVM measure?

- Single layer across the channel
- Divides layer into one or more sample cells (bins)
- Computes mean velocity in each cell
- Unmeasured areas are close to the banks

USGS

ADVMs typically measure velocities in a single layer across the channel. The measured area can be divided into one or more samples cells (also called bins), with a velocity computed for each cell. There are unmeasured areas close to the banks.

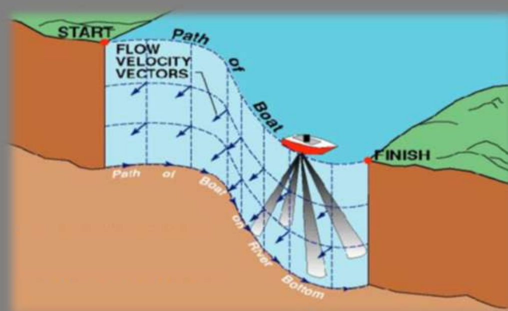
It is critical that velocity in the portion of the channel being measured can be related to the mean channel velocity for all site conditions.

Slide 22

JSC3 This is the first mention of bins. I think a slide that defines ensembles, bins, and time gating would be benificial.
jconaway, 11/27/2009

Acoustic Doppler current profilers (ADCPs)

- ADCPs are typically used to measure streamflow. Along with measuring water velocities, they can measure depths and boat speed, this allows them to measure discharge while moving across a channel.



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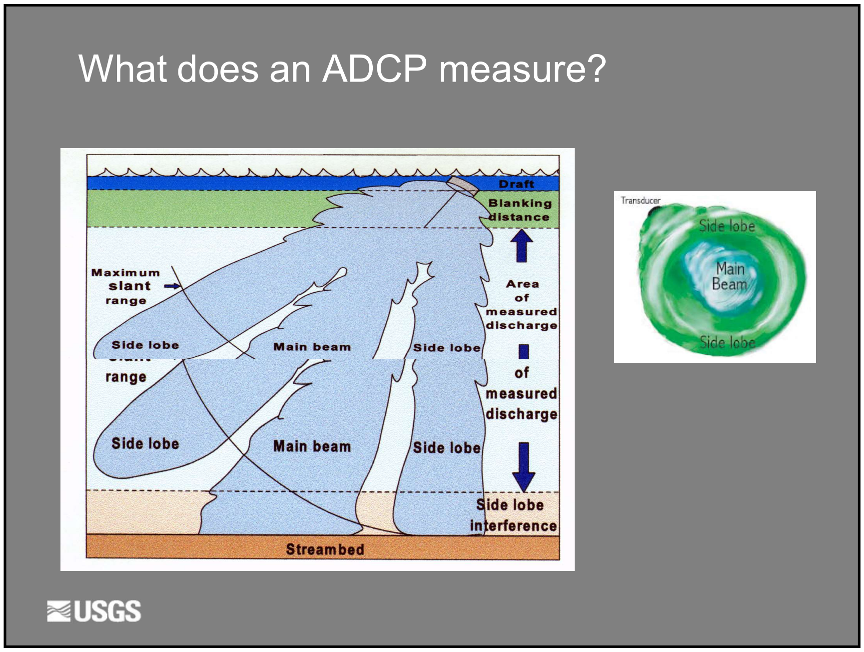
Acoustic Doppler current profilers (ADCP’s) are hydroacoustic instruments typically used to measure streamflow. Along with measuring the water velocities, they can measure depths and boat speed. This allows them to measure discharge while moving across a channel.



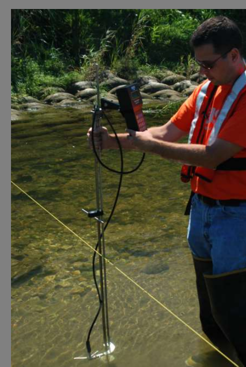
Unfortunately the ADCP is unable to measure the entire water column.

At the top, the ADCP must be immersed in the water and there is a blanking distance below the transducer where data cannot be collected. The blanking distance is a result of the transducers being both the sound source and sink. Think of a gong. When it is stuck it continues to vibrate and send out sound for a period of time. The operation of the transducers are similar. When power is sent to the transducers they vibrate to send the sound into the water column. These transducers cannot be used to listen to the backscattered acoustic energy until the ringing (vibration) has died down to a level that will not contaminate the received acoustic energy. The distance that the sound moves during this period is the blanking distance. While manufacturers have improved the ringing performance of instruments, the possible flow disturbance caused by the instrument itself, still limits how much this blanking distance can be reduced.

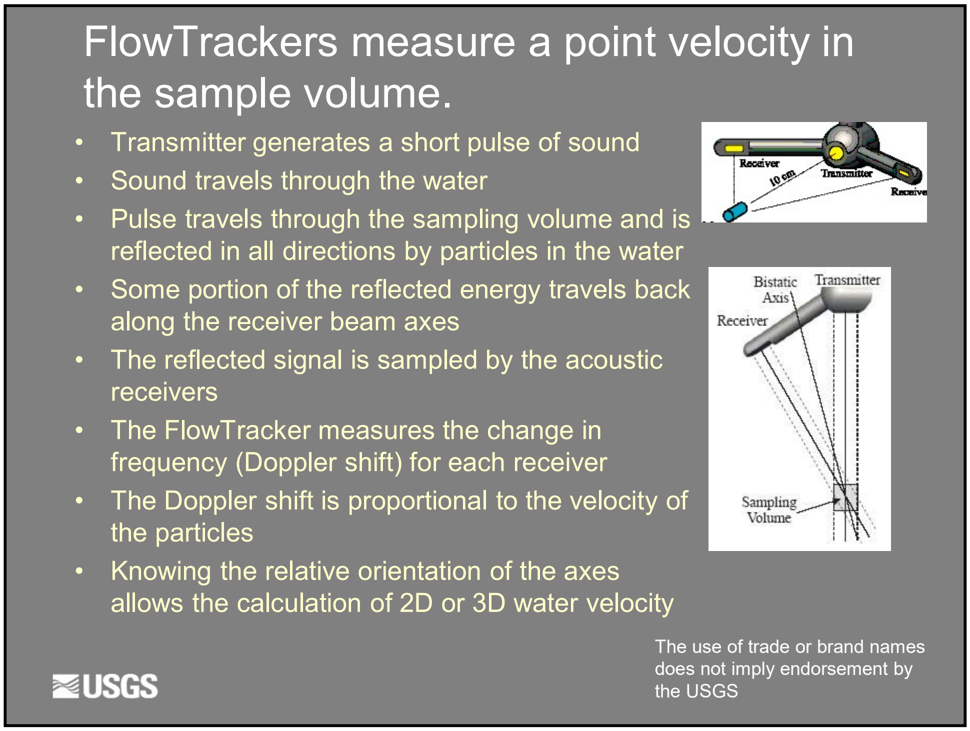
The ADCP also cannot measure all the way to the streambed. Therefore, there is an area near the bottom that cannot be measured due to side lobe interference. Which is when the return from a sidelobe beam bouncing off the bottom, overwhelms the measured water velocity in the main beam. The side lobe interference area is about 6% of the depth from the bottom for a typical instrument with a 20 degree beam angle.

Point Velocity Acoustic Instruments

- A FlowTracker is an Acoustic Doppler Velocimeter that measures point velocities and is routinely used with the mid-section method to make wading discharge measurements



Hydroacoustic instruments are also used to measure point velocities. The FlowTracker is an Acoustic Doppler Velocitimeter (ADV) that measures point velocities and is routinely used with the mid-section method to make wading discharge measurements.



The FlowTracker ADV uses one transducer to transmit the signal into the water and separate transducers to listen for the return sound. This is call a bistatic instrument. Here is a brief description of how a FlowTracker measures a point velocity:

The transmitter generates a short pulse of sound

Sound travels through the water,

The Pulse travels through the sampling volume and is reflected in all directions by particles in the water

Some portion of the reflected energy travels back along the receiver beam axes

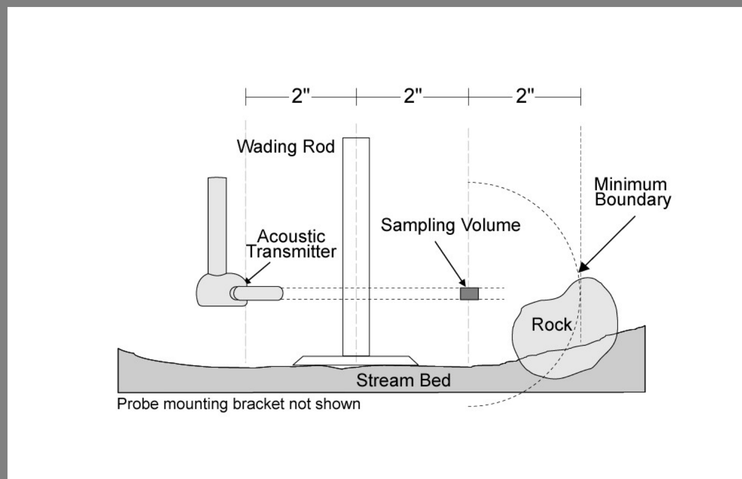
The reflected signal is sampled by the acoustic receivers

The FlowTracker measures the change in frequency (Doppler shift) for each receiver

The Doppler shift is proportional to the velocity of the particles

Knowing the relative orientation of the axes allows the calculation of 2D or 3D water velocity

Possible boundary issues with a FlowTracker



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Again, as with all hydroacoustic instruments, boundaries are a source of error. Avoid measurement sections with abrupt changes in bed topography. These changes can result because of such things as large rocks or cobbles in the measuring section. Abrupt changes in bed topography may cause boundary effects leading to inaccurate velocity measurements. The sample volume typically is 10 centimeters (about 4 inches) from the center transmitting transducer. Avoid placing the sample volume within 2 inches from any solid boundary.

Summary of Hydroacoutic Priciples

- Hydroacoustic instruments use transducers to transmit sound into the water and listen to the change in the return sound to measure a velocity in the direction of each transducer, multiple transducers are used to measure 3d velocities
- ADVM's, ADCPs, and FlowTracker ADV's are hydroacoustic instruments routinely used by the USGS

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Hydroacoustic instruments use transducers to transmit sound into the water and listen to the change in the return sound to measure a velocity in the direction of each transducer, multiple transducers are used to measure 3d velocities

Acoustic Doppler Velocity meters (ADVMs) are typically placed at gaging stations to measure insitu velocities, where a stage/discharge relationship is not valid. Acoustic Doppler current profilers (ADCPs) can measure water velocity, depth, and boat speed, and are typically used to make moving boat discharge measurements. Point velocity meters, like the FlowTracker Acoustic Doppler velocitimeters (ADVs) are used in wading streamflow measurements using the midsection method.

The Class Assessment Follows.

- The assessment that follows contains four questions.
- Once you have successfully completed tests for all modules you will be given instructions on how to print out a certificate that documents successful completion of the Surface Water Procedures Training Class

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Lesson Assessment

Quiz - 4 questions

Last modified: Sunday, July 23, 2017 at 1:27:25 PM

Properties

On passing, 'Finish' button:	Goes to next slide
On failing, 'Finish' button:	Goes to next slide
Allow user to leave quiz:	At any time
User may view slides after quiz:	After passing quiz
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End of class module

- Please close this window and take the next module, if needed.

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