RECLAMATION

Managing Water in the West

WRRL Contributions to Water Conservation

Counting Every Drop and Making Every Drop Count

U.S. Department of the Interior
Bureau of Reclamation

Water Conservation

- **PRIMARY OBJECTIVE: Obtain the maximum benefit from every drop of diverted water**
  - Deliver the right amount of water to the right place at the right time
  - Prevent water loss from delivery system
  - Make best use of the water in the field

WRRL Water Conservation Focus

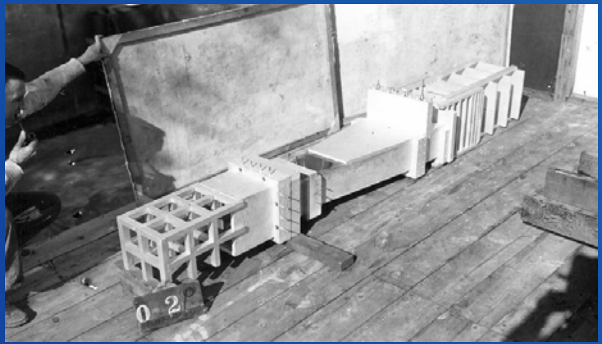
- Deliver the right amount of water to the right place at the right time
  - Minimize diversion of “extra” water to cover the times when we cannot match deliveries to needs (administrative spill)
- Water Measurement
  - Knowing flow rate at points of control is necessary to manage operations
  - Accurately accounting for delivered water promotes equitable and economical use of water
- Canal Operation and Control
  - Get the water to the proper place at the proper time

Overview

- Water Measurement History
- Canal Automation History
- Today’s Areas of Emphasis

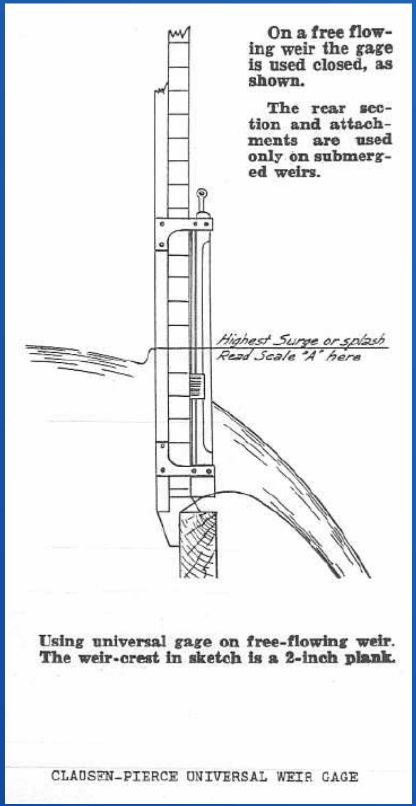
Early Water Measurement Work

- Water measurement was important R&D topic from the beginning of the lab
- Ralph Parshall had developed the Parshall flume 1922
  - Widely used by Reclamation and others worldwide
  - Self-cleaning
  - Standardized dimensions, which eased construction compared to devices that had come before
- Lab made many studies of “unique” Parshall flumes and other similar devices
  - 1933 at Fort Collins, Jacob Warnock studied a unique venturi-meter/ venturi-flume hybrid for Owyhee Project (HYD 1.5)



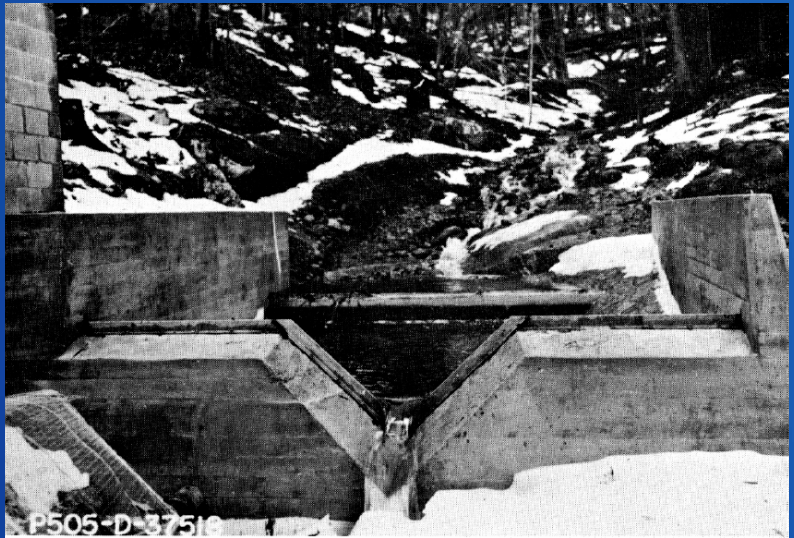
Sharp-Crested Weirs

- Already a well established technology when lab began. Studies focused on accessories and adaptations
  - HYD-209, 1946 – Clausen-Pierce weir rule



Compound Weirs

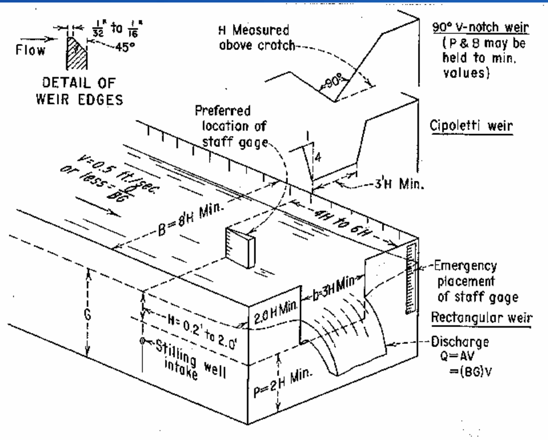
- **HYD-505, 1963 – Compound Weir Studies by J. Bergmann**



A. Compound weir, 90° V-notch with horizontal extensions, used to measure stream flows by the United States Department of Agriculture Forest Service.

Weir Boxes

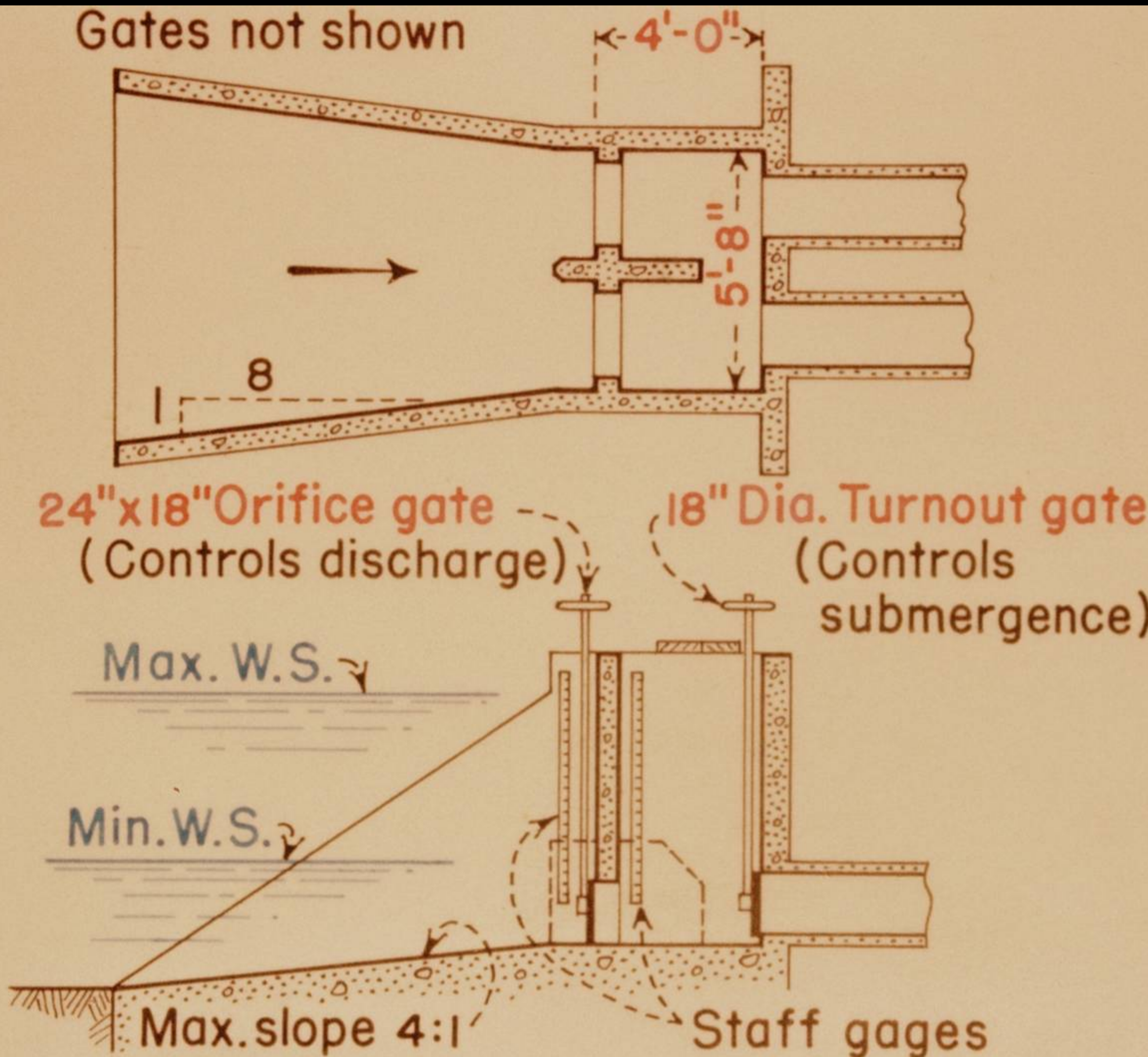
- **Standard weir box to obtain fully contracted flow was often too large**
- **Several studies have attempted to develop calibrations for non-standard smaller weir boxes**
  - **HYD-396 (1954) Hydraulic Model Studies of Small Weir Box Turnout Structures for General Irrigation Use**
  - **REC-ERC-72-31 (1972) Hydraulic Laboratory Studies of a 4-foot-wide Weir Box Turnout Structure**
  - **R-90-19 (1990) Lower Colorado River Authority Water Box Calibrations**



WEIR PROPORTIONS
RECTANGULAR, CIPOLETTI AND 90° V-NOTCH

Constant-Head Orifice Turnouts

- Two-gate orifice-type measurement and control structure.
- Standard drawings developed by Reclamation in 1940 (Dwg. 40-D-3672 and 40-D-3673).



PLAN I

CONSTANT HEAD ORIFICE TURNOUT

CHO Application and Calibration

- Several hundred built in early 1940's on projects such as Altus, Mirage Flats, Tucumcari, etc., using discharge tables based on an assumed coefficient of 0.66.
- Laboratory study by B.R. Blackwell in 1946 (Calibration of the Constant-Head Orifice Turnout, HYD-216) showed actual coefficients to range from 0.685 to 0.715, with an adopted average of 0.700
(6% higher than previously assumed)

Constant-Head Orifice Turnout

- 1974, Design of Small Canal Structures gave tables for other size CHOs, but they were based on the old lab studies
- PAP-290 1973 Summary of Tests of an Automated Constant Head Orifice Turnout

Commercial Meter Gates

- **Popular in 1950s**
- **HYD-314 1951 Flow Characteristics and Limitations of Armco Meter Gates**

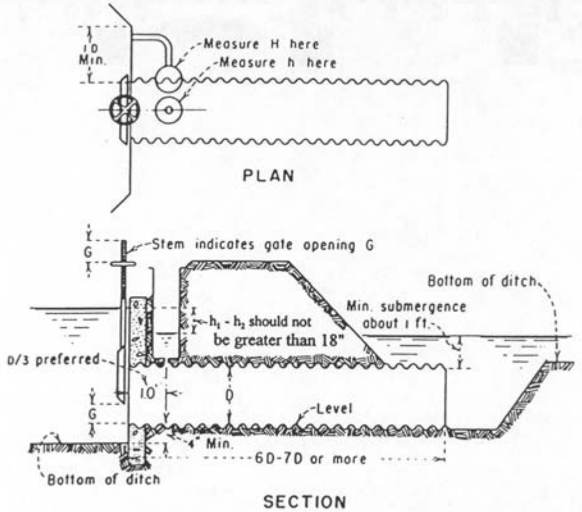


Figure 9-9.—Typical meter gate installation.

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Deflection Meters

- **Popular in 1950's and early 1960's.**
- **Closed pipe version manufactured by Sparling tested in the lab in 1949 (F-672).**
- **Open channel version made by Pendvane tested in lab in 1962 (R-HYD-10, *Laboratory Studies of the Pendvane Flowmeter,* T.J. Isbester).**
- **Pendvane found to be highly susceptible to wind effects (errors up to 100%).**

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Water Measurement Manual

- As early as 1913 Reclamation had published guides for water measurement
- Need for training was great
  - Laboratory provided many workshops that included flow measurement training
- Course notes were published first in HYD reports, and eventually in the first edition of the Water Measurement Manual 1953
- 11,000 copies distributed

WMM, 2nd edition, 1967

- 2nd edition written primarily by Bill Simmons and Al Peterka
- Added new information about Parshall flumes
- Added Kindsvater-Carter weir relationships
- Information on CHOs

- Reprinted 8 more times up to 1993

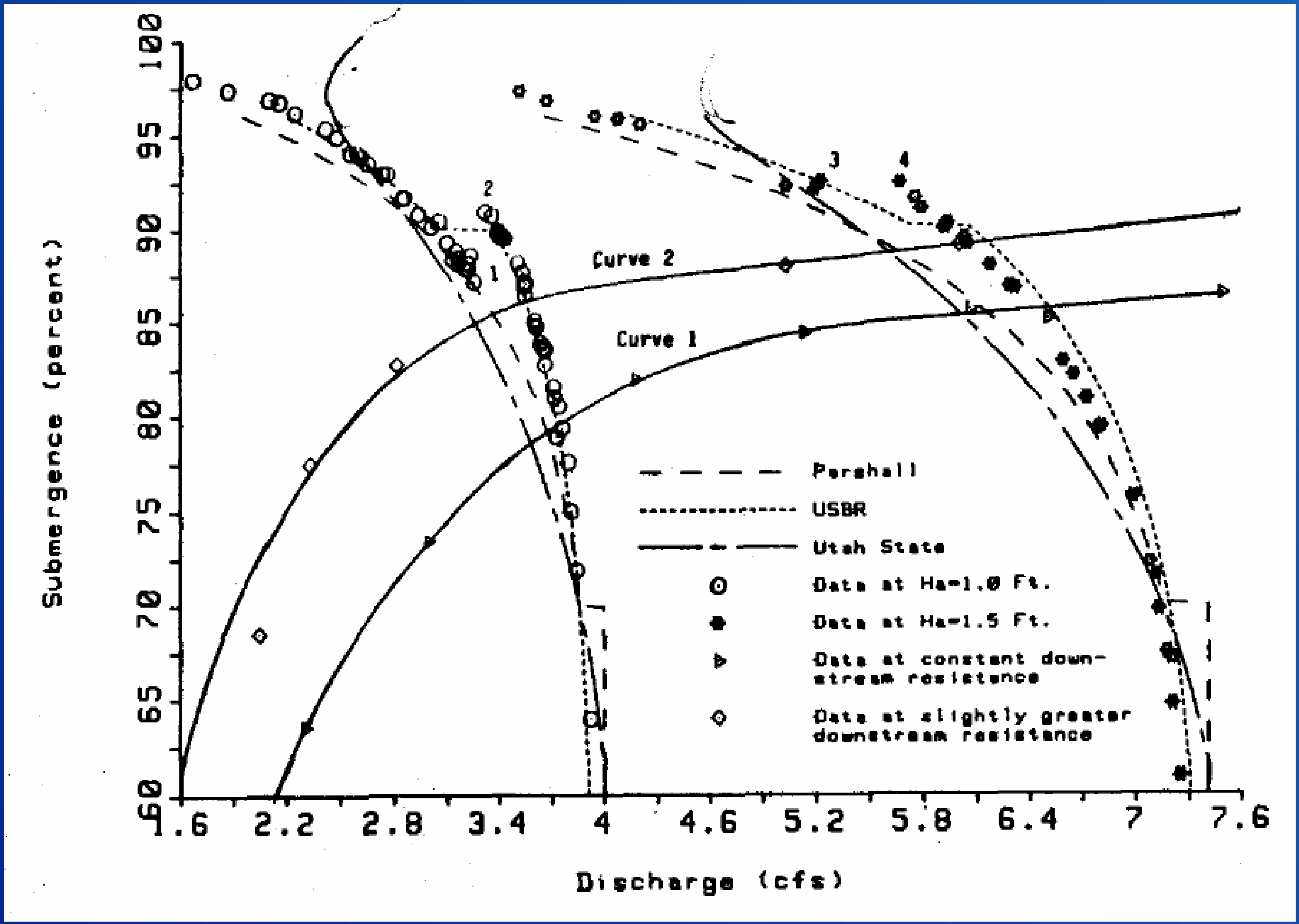
WMM, 3rd edition, 1997

- Manual now became the official water measurement publication for both Reclamation and USDA
- Russ Dodge (USBR) and John Replogle (ARS) led effort. Many current members of the laboratory contributed to this edition.
- New manual added information about acoustic meters, measurement accuracy, measurement with tracers
- Dropped a lot of detail on Parshall flumes, because they had fallen out of favor, added information on more modern devices
- Dropped the old “pocket book” format

Later Parshall flume studies

- As Parshall flumes aged, many people became interested in things that affected their accuracy (lateral and longitudinal tilt, submergence, poor approach flow)
- Late 1980s Hilaire Peck led studies of submerged flow in Parshall flumes that revealed hysteresis zone in submerged flow in the 1-ft flume

Parshall flume hysteresis



Parshall flume hysteresis

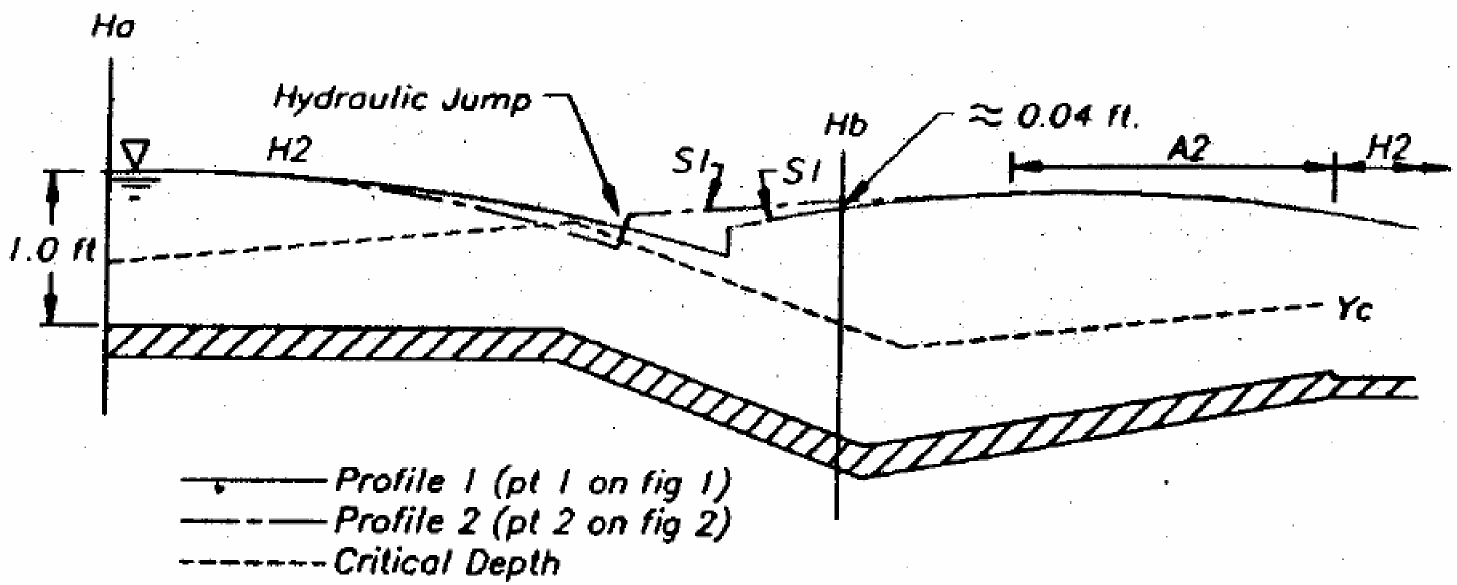


Figure 2. - Flow profiles in test flume (1-ft throat width).

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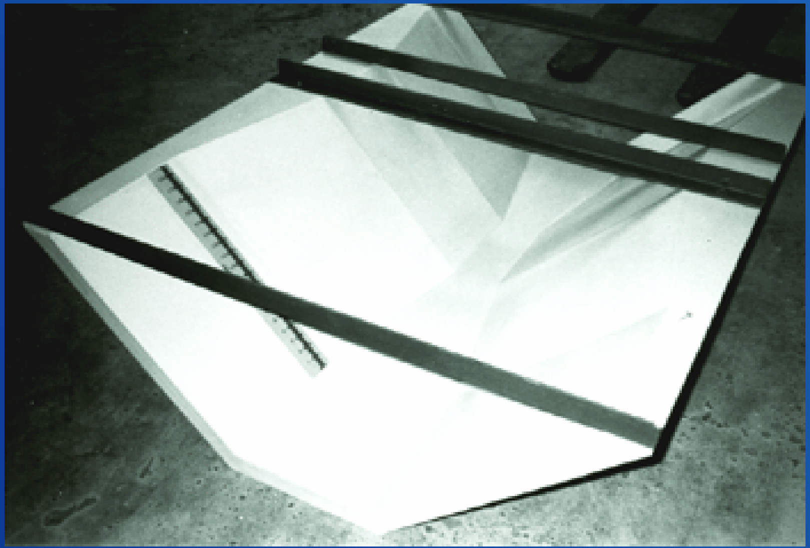
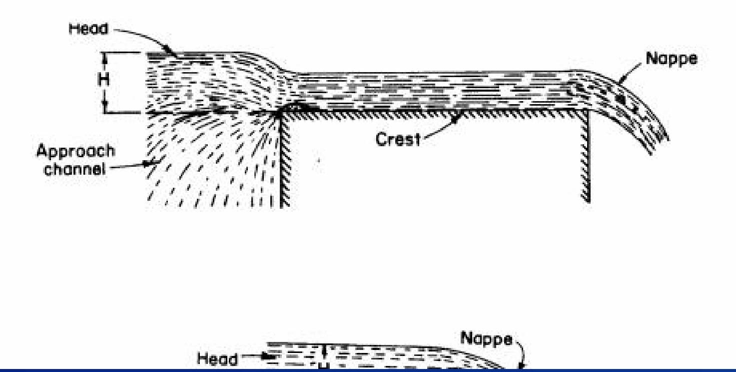
Modern Flumes

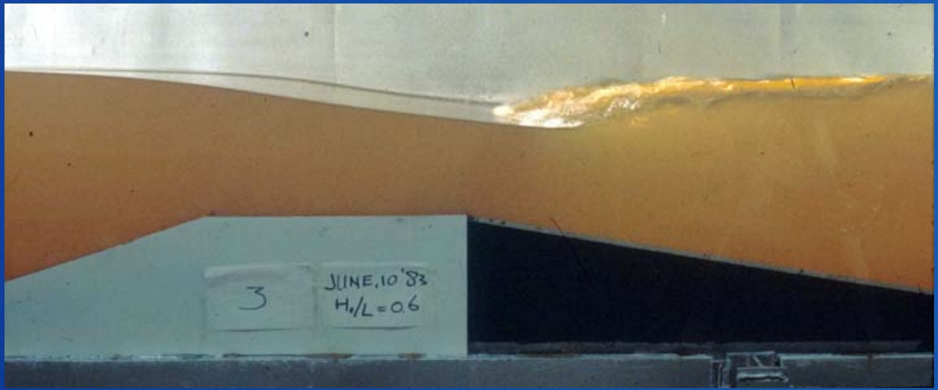
- Efforts were made by many to simplify Parshall flumes
  – Cutthroat flume
  – REC-ERC-72-14 1972 Laboratory Study of a Flat-Bottom Trapezoidal Venturi Flume



Long-Throated Flumes

- **Early 1980s the lab got involved in studies of "ramp flumes", under development since early 1970s by John Replogle (ARS) and Rien Bos (ILRI).**





Long-Throated Flumes

- "Modern" flumes that could be calibrated theoretically with aid of computer analysis
- More tolerant of submergence
- More economical
- Adaptable to special situations

WRRL Work on Long-Throated Flumes

- Lab studies by Russ Dodge of early prototype structures
- Infamous field trip to Kalamity Falls to measure velocity profiles on the flume in “A” Canal

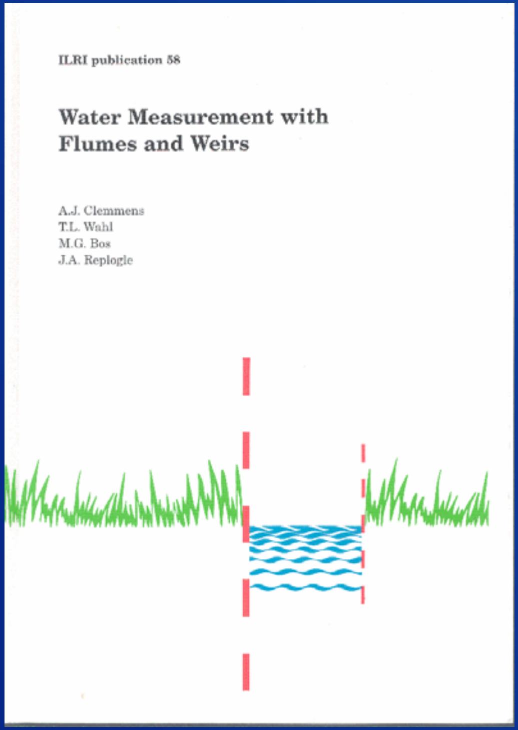
Long-Throated Flume Software

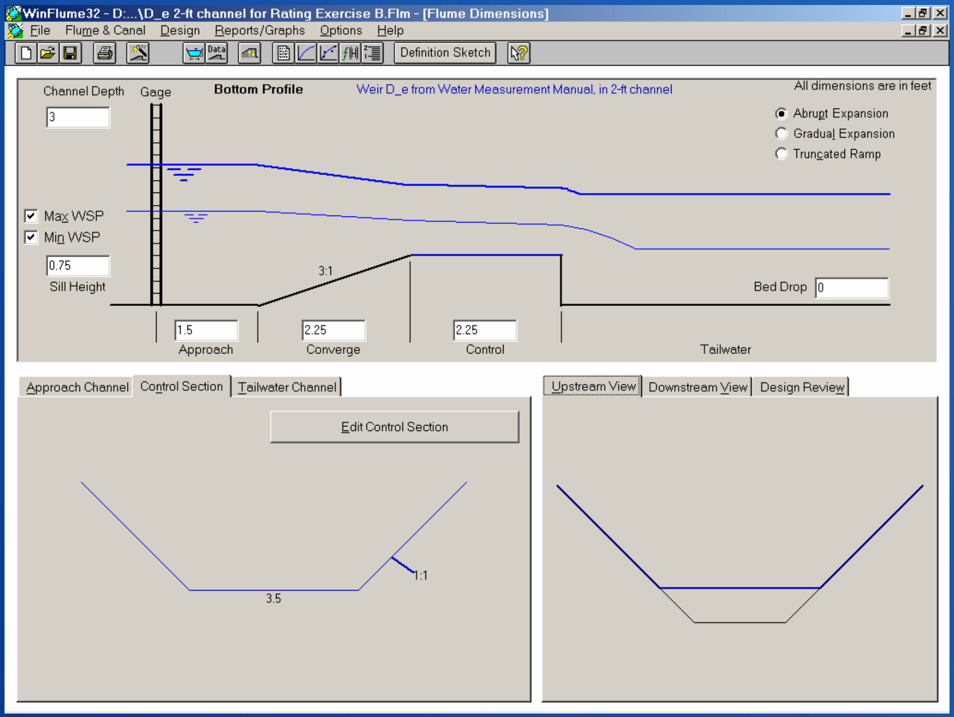
- John Replogle developed FORTRAN codes to calibrate his flumes

- Early 1990s ARS and ILRI contracted for the development of an interactive computer program
- DOS-based software had a short lifespan

WinFlume

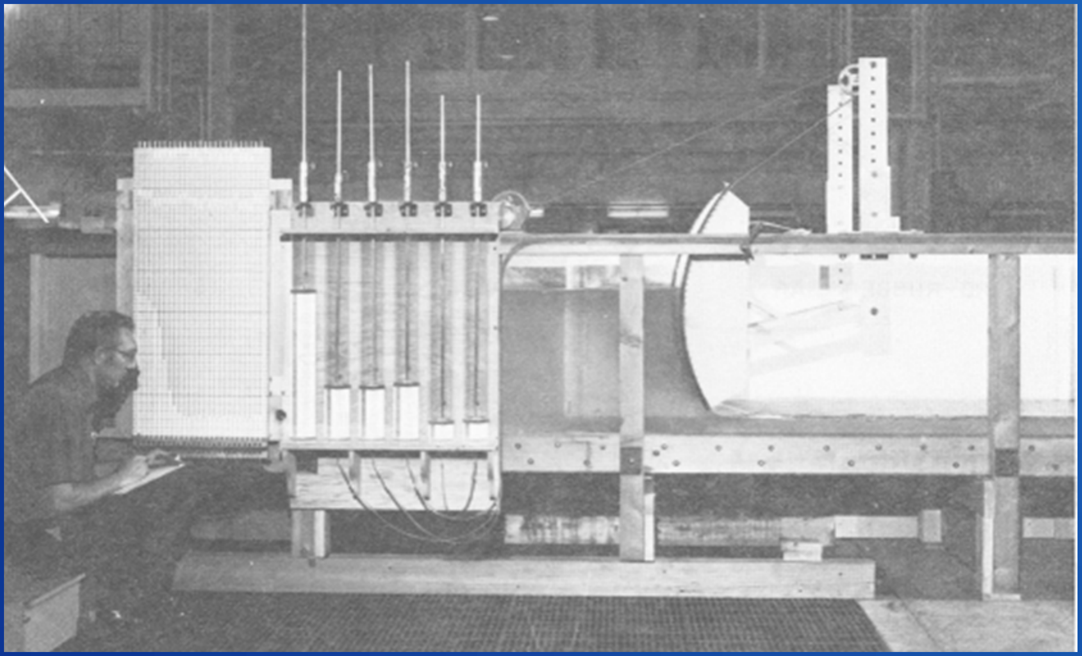
- 1997 we began with ARS's assistance to develop a Windows version, WinFlume





Measuring Discharge with Radial Gates

- Clark Buyalski ran radial gate tests in lab for several years, compiling 2600+ test runs on 9 model gates through 1983



RADGAT

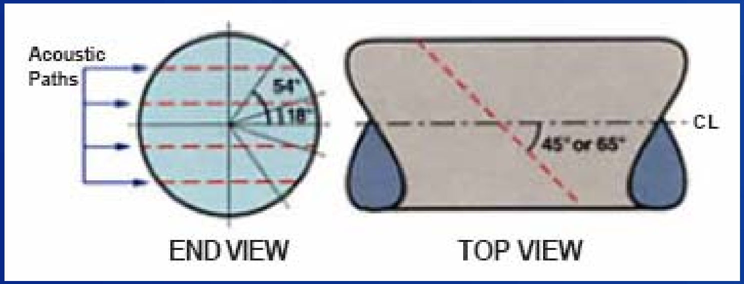
- RADGAT computer program, REC-ERC-83-9, Discharge Algorithms for Canal Radial Gates
  - Mainframe
  - Ported to DOS in early 1990s by Dave Rogers
- New studies in partnership with ARS are now underway, and new software is being written this summer
- Reanalysis of Buyalski's data has contributed to the current work

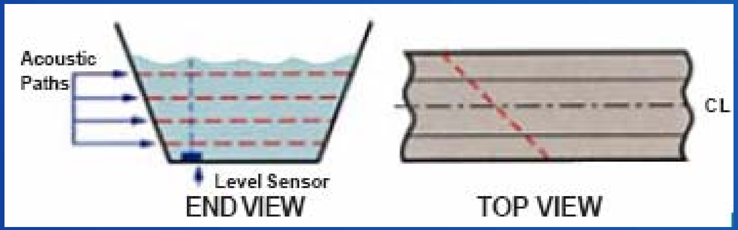
Acoustic Measurements

- Lab began studying acoustic flow meters in the early 1970s
- R&D has taken place in private industry
- Lab efforts have been focused on applications
  - Hydraulic laboratory measurements
  - Evaluating selective withdrawal and tracking movement of plumes in lakes
  - Discharge measurement on big rivers
  - Penstocks and pipelines
  - Canals
  - Small streams

Acoustic Flow Measurement

- **Transit time**
  - Measure time of travel through moving water from one point to another
  - Knowing travel time and distance traveled, we can compute velocity along traveled path

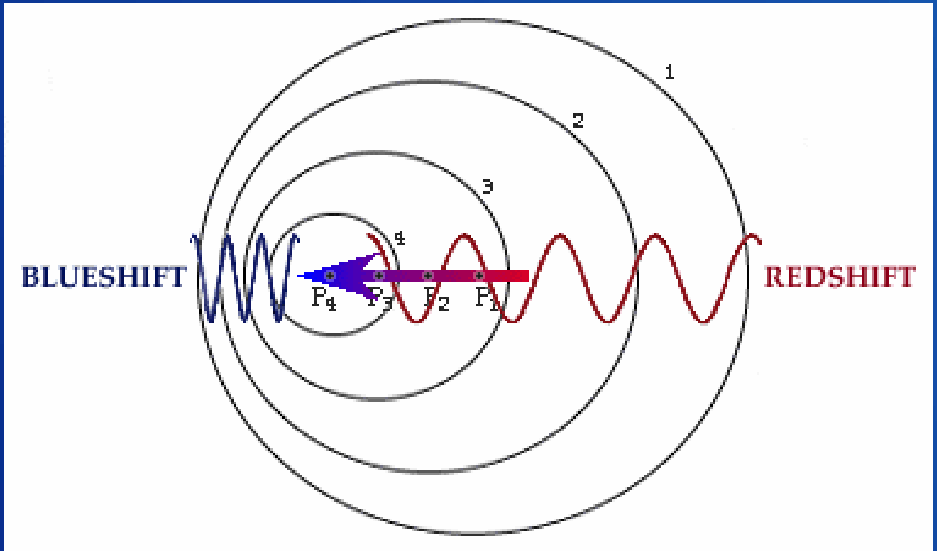




Graphics obtained from www.accusonic.com

Acoustic Flow Measurement

- Doppler shift
  - Measure frequency shift caused by particles in the flow that reflect a signal of a known starting frequency



Current-Metering

- Replacing Price AA current meters
- SonTek FlowTracker acoustic Doppler current meter
  - Laboratory instrument finding its way to the field

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ADCP

- Acoustic Doppler current profiler
  - Once a bulky research instrument
  - Now much smaller and easier to use (and cheaper!)

ADCP Measurement Concept

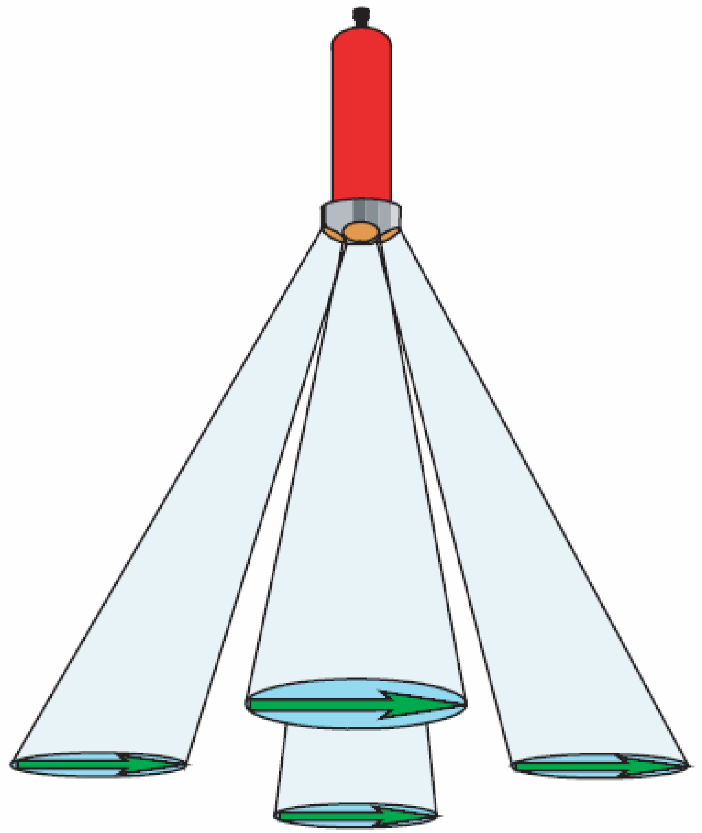

Figure 1.13. Acoustic Doppler current profiler measuring a homogeneous velocity field.

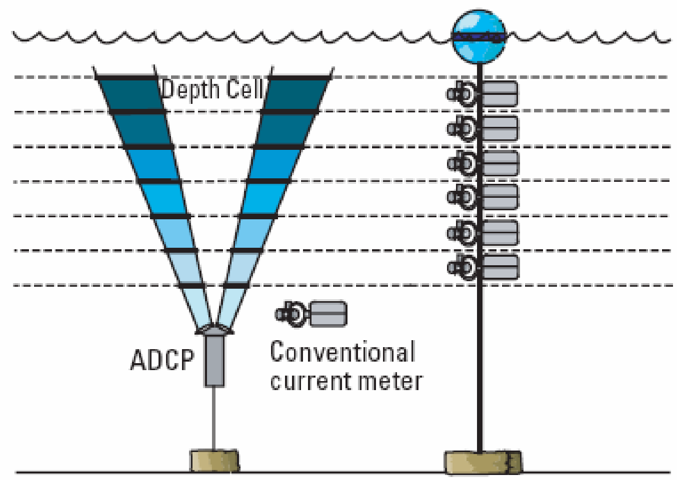

Figure 1.15. Analogy of a conventional current-meter string to an acoustic Doppler current profiler (ADCP) profile.

Discharge Measurements Using a Broad-Band Acoustic Doppler Current Profiler

by

Michael R. Simpson

United States Geological Survey
OPEN-FILE REPORT 01-1

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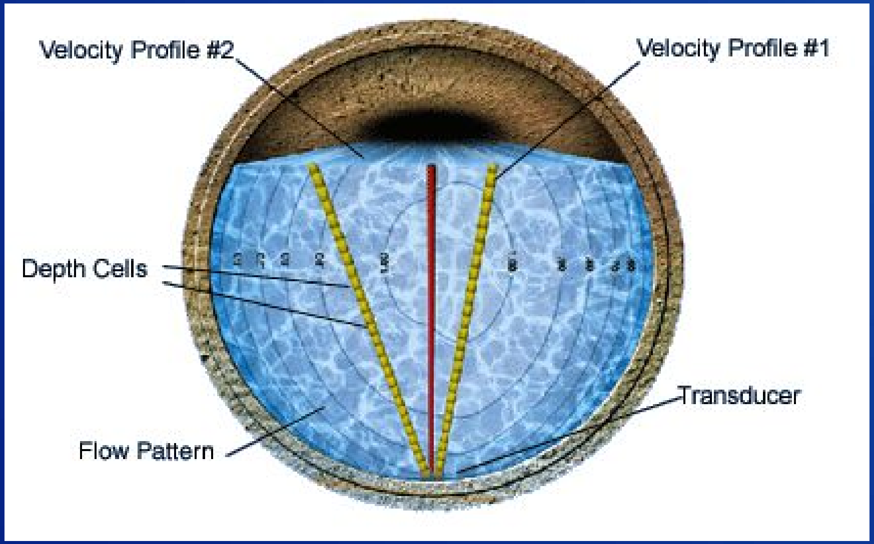
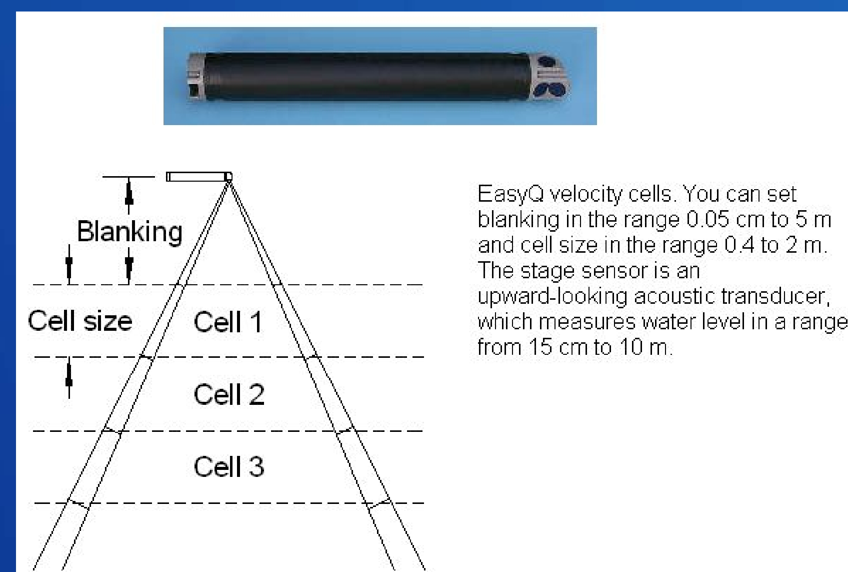
Bottom-Mounted Acoustic Profilers

- Direct discharge measurement



Side-Looking Current Meters

- **Use simplified versions of ADCP technology**
  - Measurements still made in bins, but they are typically oriented horizontally
  - Common instrument for index velocity applications



Water Measurement Summary

- Finding better ways to apply old technologies
- Finding new applications for new technologies
- Meeting the demand for:
  - Measurement at more sites
  - Higher accuracy
  - Continuous monitoring
  - Measurement in difficult conditions

Historical Developments in Canal Operations

- Early projects operated entirely by hand
- Canals sized to deliver maximum flows, but did not necessarily have flexibility to be operated in ways that could be most efficient with the water
- Early attempts at automation began in 1950s
  - Crude, but immediately successful
  - Littleman and Colvin controllers

Interdisciplinary Water Systems Automation Team, 1970s

- Lab participants included Buyalski, Falvey, Ehler, Rogers
  - Development of algorithms
  - Designing for efficient operations, not just max flow
  - Technical assistance to districts
  - Continued tradition of publishing what we learned in the form of the Canal Systems Automation Manual (2 volumes)

Evolution of Better Canal Operations

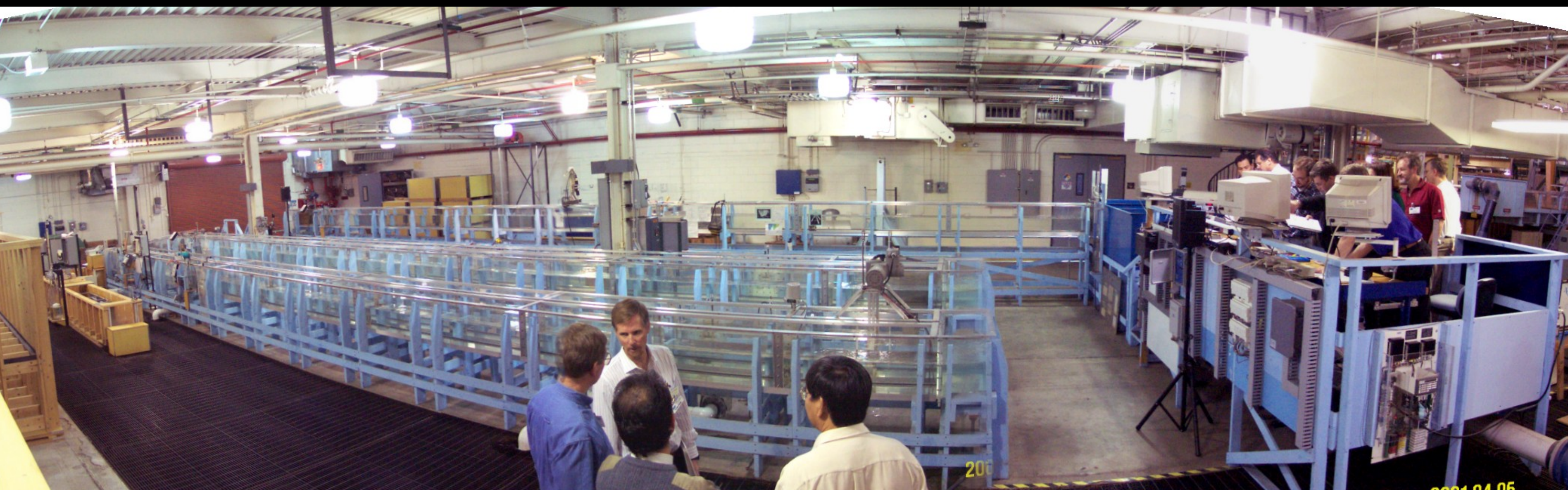
- As projects grew and we gained operating experience, we began to think about different ways to operate canals
  - Scheduled systems in which we (tried to) rigidly control both supply and demand, and route water from origin to delivery destination
  - Upstream control when demand can vary easily to react to supply changes
  - Downstream control when supply (e.g., from a reservoir) can be varied to react to demand changes
  - Constant-volume operation to make canal operate almost like a closed pipeline
- More sophisticated methods require automation and less sophisticated still benefit from it

Canal Control Algorithms

- Little-Man
- Colvin
- EL-FLO and EL-FLO+Reset
- P+PR
- BIVAL
- Dynamic Regulation
- Gate Stroking

Canal Model Test Facility

- Control algorithm development spurred the construction of a canal model test facility in the north end of the lab
- Removed in 1994 and replaced by the current facility
  - Test control algorithms
  - Test and demonstrate RTUs and sensor technologies
  - Provide training in canal operations and automation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Today's Focus is on Improving Water Management Capabilities

- Flow Measurement
- Delivery System Modernization

Flow Measurement: 21st Century Demands

- Measurement at more sites
- Higher accuracy
- Continuous monitoring
- Measurement in difficult conditions

Low-Cost On-Farm Measurement

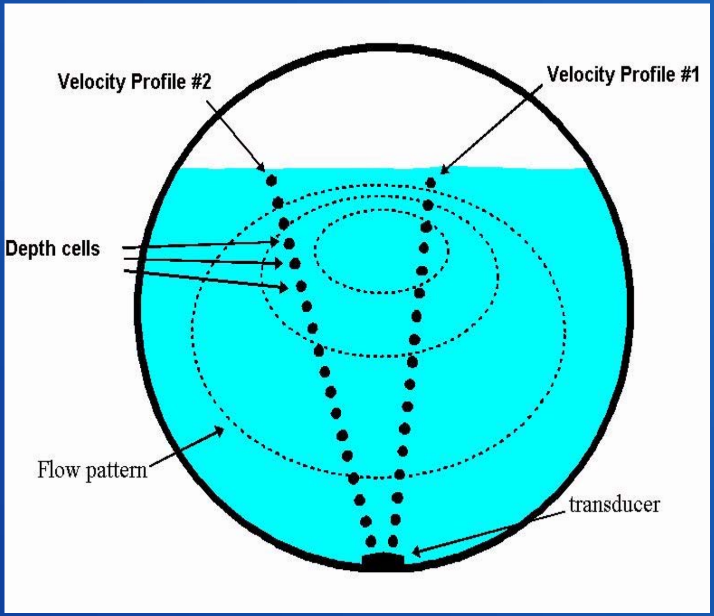
Ramp Flume in Gated Pipe

Irrigation Pipe Elbow Meter

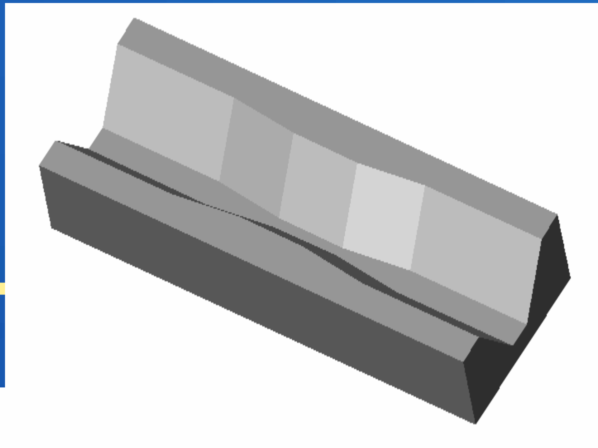
Venturi Meter Made from PVC Fittings

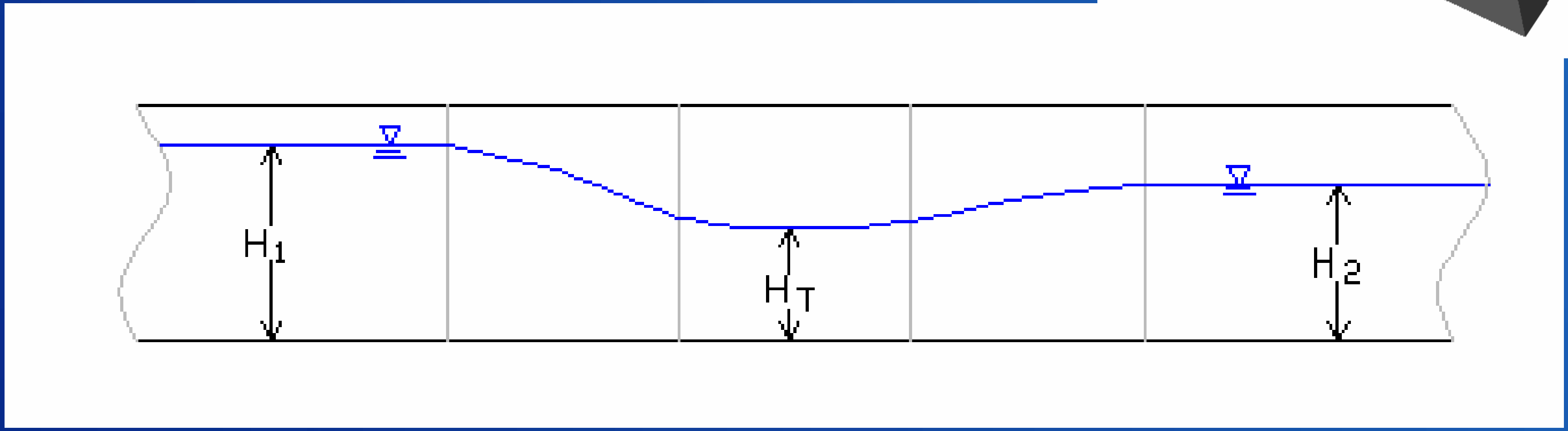
Measurement at Locations with Low Head Availability

Acoustic Doppler Profiling



Submerged Venturi Flume





$H_2 < 80\%\ H_1$: Unsubmerged, need only H_1

Submerged or Unsubmerged, if H_1 & H_T known:

$$Q = C_d * \frac{A_1 * A_T}{(A_1^2 - A_T^2)^{0.5}} * \left(\frac{2g}{\alpha} * (H_1 - H_T)\right)^{0.5}$$

Software Development

- Make Technology Accessible
  - WinFlume
  - Radial Gate software
  - Spreadsheet for Kindsvater-Carter weir ratings

Canal Modernization

- Reliable & Accurate Delivery
- Delivery Flexibility
- Better Match of Supply to Demand
- Reduce Long Term Costs
- Maximum Benefit from Available Supplies

Greater Delivery Precision Needed

Traditional Application:
Furrow Irrigation

Emerging Technology:
Subsurface Drip

Values of Modernization for Irrigation Districts

Reduced Operational Costs

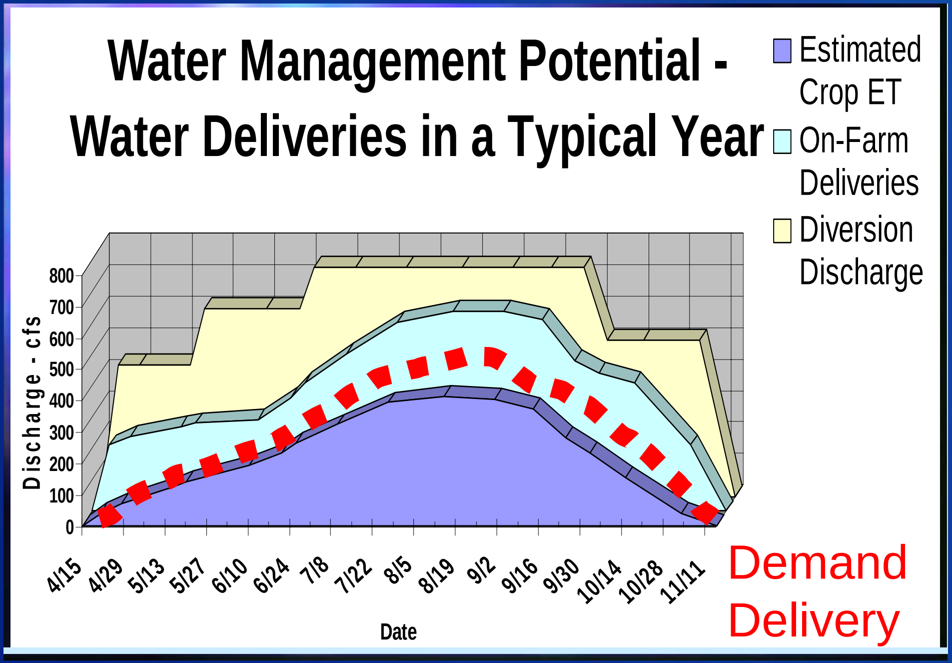
Remote communication can cut needs to physically visit sites

Reduced Opportunity Costs

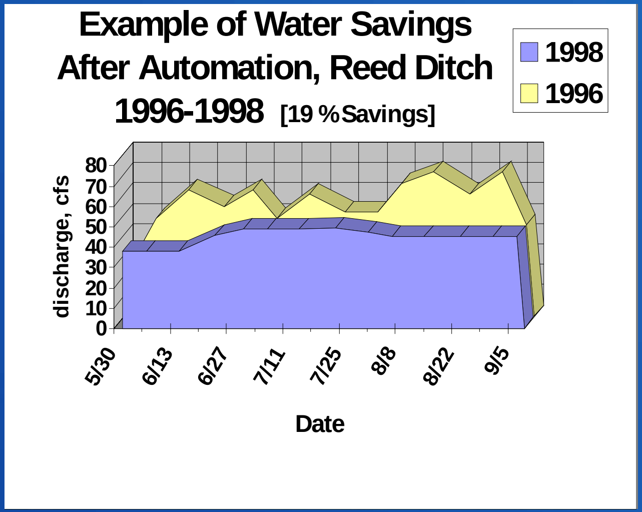
Diminish lost realization of value due to spills, etc.

Maximize Use of Limited Supplies

Water Savings Potential



Demand Delivery



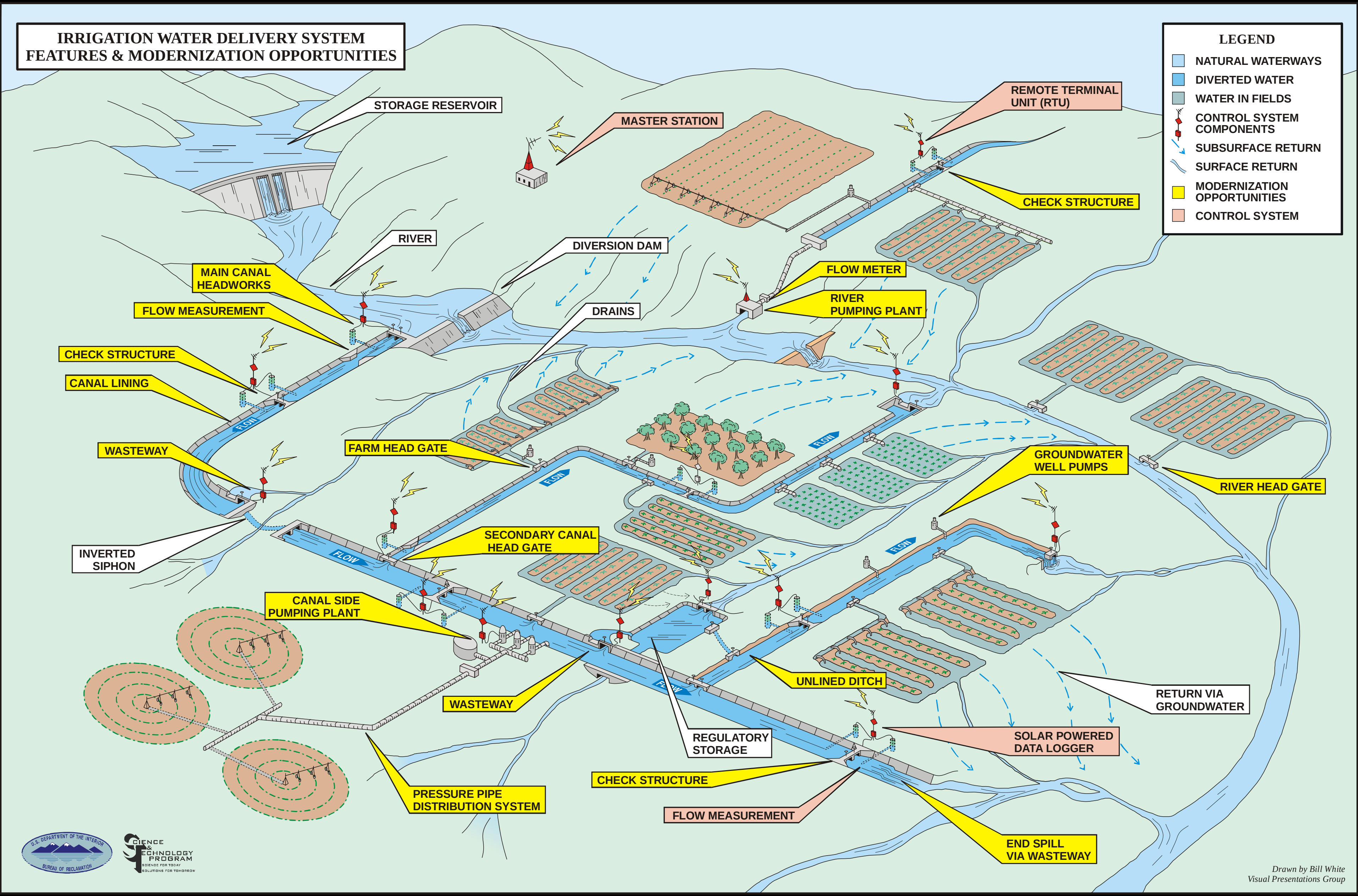
Demand Driven Operations make Water Available for Other Uses

RECLAMATION

Where Do Opportunities Lie?

- Canal Headworks
- Flow Measurement Sites
- Wasteway Spills
- Secondary Canal Headgates
- Intermediate Control Points
- Storage Reservoirs
- Farm Headgates (turnouts)
- Screening Debris to Allow Use of New Application Methods

RECLAMATION


IRRIGATION WATER DELIVERY SYSTEM
FEATURES & MODERNIZATION OPPORTUNITIES
LEGEND
NATURAL WATERWAYS
DIVERTED WATER
WATER IN FIELDS
CONTROL SYSTEM COMPONENTS
SUBSURFACE RETURN
SURFACE RETURN
MODERNIZATION OPPORTUNITIES
CONTROL SYSTEM
STORAGE RESERVOIR
MASTER STATION
REMOTE TERMINAL UNIT (RTU)
CHECK STRUCTURE
RIVER
DIVERSION DAM
MAIN CANAL HEADWORKS
FLOW MEASUREMENT
FLOW METER
RIVER PUMPING PLANT
DRAINS
CHECK STRUCTURE
CANAL LINING
FLOW
WASTEWAY
FARM HEAD GATE
GROUNDWATER WELL PUMPS
RIVER HEAD GATE
INVERTED SIPHON
SECONDARY CANAL HEAD GATE
CANAL SIDE PUMPING PLANT
WASTEWAY
UNLINED DITCH
RETURN VIA GROUNDWATER
REGULATORY STORAGE
SOLAR POWERED DATA LOGGER
CHECK STRUCTURE
PRESSURE PIPE DISTRIBUTION SYSTEM
FLOW MEASUREMENT
END SPILL VIA WASTEWAY
U.S. DEPARTMENT OF THE INTERIOR
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SCIENCE & TECHNOLOGY PROGRAM
SCIENCE FOR TODAY
SOLUTIONS FOR TOMORROW
Drawn by Bill White
Visual Presentations Group

Evolutionary Development

- Start Small
- Start Simple
- Gain Success and Momentum
- Expand at a Comfortable Pace

- Districts That Take Ownership Succeed!
  - WRRL role is to facilitate that process

Training Courses

Modern Methods in Canal Operation and Control

Basic Principles and Developments in Flow Measurement

On-Site Workshops/Special Activities

Northern Colorado Workshop, 2003

International Canal Class Study Tour, 2005

DRI-TCID Study Tour, 2005