STREAM SYSTEMS TECHNOLOGY CENTER

STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

January 1998

Development of an Integrated Water-Level Sensor and Data-Logger System

Water level information is an essential part of many water management programs. Water level data is the basis for streamflow, precipitation, and groundwater measurements. The water levels of streams, rivers, and lakes provide information about variables such as snowmelt, flood peaks, and other changes in hydrologic regimes.

Water level is sometimes measured by an individual using a depth meter and physically measuring the water depth in the body of water or in a stilling well near the water source. The alternative to this method is to use expensive instruments and link them to data loggers that continually monitor water level. Each data logger must be connected to several sensors by coaxial cable or twisted pair wires. This method has several disadvantages:

- Loss of a single data logger can mean loss of many data channels.
- Using connecting wires is problematic in elevated sites due to lightning and loss of information because of long wires.
- Wires interfere with natural wildlife activity.
- Expense limits the number of sites that can be monitored.

To overcome these problems, the University of Washington and the USDA Forest Service, Rocky Mountain Research Station, Stream Systems Technology Center, entered into a Challenge Cost Share Agreement to develop a low-cost water-level sensor and recorder.

The University of Washington was interested in developing low-cost sensor technology to apply to forestry situations and to take advantage of the education opportunities afforded in developing and applying this technology through their Electrical Engineering Department.

The Forest Service was interested because it needs high quality, low-cost technology to measure stream levels. To be most useful, the data should be in an automated format so it can be processed easily and quickly on desktop computers. The technology needs to be durable enough to withstand field conditions, have a minimum of moveable parts, and be easy to maintain and operate.

The proposed design was based on core concepts developed at the University of Washington for low cost, distributed,

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The PRIMARY AIM *is to exchange technical ideas and transfer technology among scientists working with wildland stream systems.*

CONTRIBUTIONS *are voluntary and will be accepted at any time. They should be typewritten, single-spaced, and limited to two pages. Graphics and tables are encouraged.*

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A Vision of Future Stream Data Collection

Adapted from material prepared by
Dr. Kelin Kuhn[1]
University of Washington
Department of Electric Engineering

Visualize the following scenario:

The field engineer or hydrologists begins the day with a backpack full of sensor units. As she goes to each site, she writes the serial number of the unit down into her notebook and installs the unit. She then retrieves the unit on site, (which has been collecting and logging data for a week), double checks that the on-site unit has the same serial number as the one she left there last week, and tosses it in her pack. In a few hours, she has traded all of her empty sensors for full ones.

She then returns to the laboratory, takes off her field gear, and dumps all the sensors into a bucket of water, and washes off the mud. She then tosses them on a towel to dry. Next, with a cup of coffee in hand, she fires up the docking station. She flips the switch on the docking station from PC to MAC and plugs in her PowerBook (Real units will be compatible with many formats and computers). Sitting comfortably, and sipping her coffee, she inserts groups of sensor units into the docking station. Each unit uses its LED to communicate with the docking station and the file transfer begins. Fifteen minutes later, ready for a second cup of coffee, all the data from the 30 sensors is downloaded to her PowerBook for analysis. Once all the sensors are read, she racks them up in their inductive charging tray to recharge the batteries for the next trip.

[1] *Dr. Kuhn is now employed by Intel Corporation.*

water monitoring instruments (see sidebar). The instruments developed were to be sufficiently low cost to make them economically feasible for placement in national forest settings, in existing stilling wells, and pipe crest-gages. Extensive deployment of these instruments would allow the Forest Service to gather data on flow levels in the National Forests and to use this data for planning purposes and for instream flow determinations.

In the spring of 1994, Dr. Susan Bolton, University of Washington, Forest Management and Engineering Department and Center for Streamside Studies, was exploring the problem of how to measure water at multiple sites with a limited budget. She found an inexpensive Australian-made, capacitance-based water-lever sensor, but it was not reliable enough for her needs. Susan contacted the Chair of the Electrical Engineering Department and asked if there were any classes that needed a real-life design problem. She was put in touch with Dr. Kelin Kuhn, Department of Electrical Engineering. Coincidently, Dr. Kuhn had a graduate student, Brian Read, who had suggested just such a device but was unsure whether there was any market for it. In this manner, the collaborative relationship between the College of Forest Resources/Center for Streamside Studies and the Department of Electrical Engineering at the University of Washington began.

Brian Read built a hand-held demonstration model to show proof of concept. The Stream Systems Technology Center became involved through a Challenge Cost Share Agreement, and Brian proceeded with prototype development. The design specifications included low cost, 2 mm resolution, non-volatile data storage, data recording only if water level changes, and a profile narrow enough to fit inside a 2 1/4" I.D.

stilling well (i.e., usable as a piezometer or to fit inside a crest-gage installation).

The sensors are independent units containing their own data loggers. The sensor head incorporates a microprocessor, batteries, and communication link.

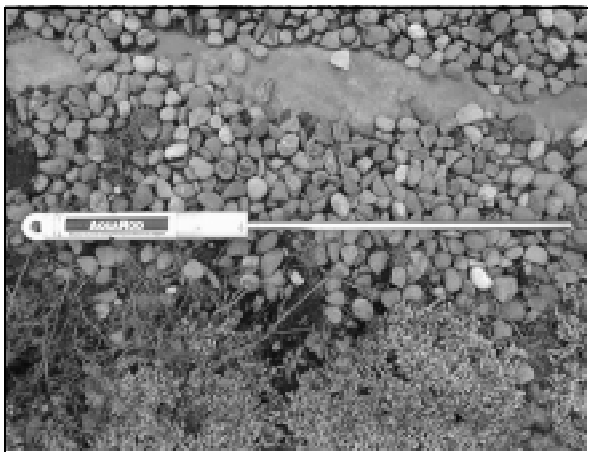
The instrument consists of two main parts: the pod, which contains the electronics for data acquisition and logging, and the rod, which is the capacitance gage used to determine water depth.

The rod is a stainless steel tube with a smaller diameter, stainless steel rod in its center. The tube and the rod form a cylindrical capacitor with air as the dielectric. The top and the bottom of the tube are perforated to allow water to enter and air to escape. If the sensor is placed in water, the water displaces the air and significantly changes the capacitance (water has a dielectric constant 80 times greater than air). The output of the circuit formed by the sensor and an internal resistor is used as input into the first capture and compare channel. The time-constant of the resulting circuit is then used to determine the effective capacitance (and thus the water level).

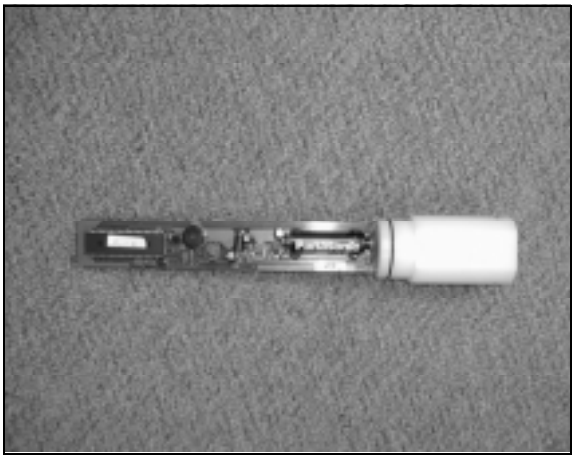
Dr. Bolton notes that some of the components thought difficult to design and build, were less of a problem than some that were assumed easy. For instance, it was believed that the materials science aspect, the dielectric coatings of the tube, would be easier to design than the electronics for a self-contained data logger, but the opposite was true. The dielectric coating dilemma took 18 months to solve. Coatings worked fine if not subjected to freezing but chipped if frozen, which interrupted the electric charge for the capacitance measurement. The electronics problems succumbed in much less time than anticipated; the greatest problem was getting chip manufacturers to send cutting edge chips as promised.

After much work, Read discovered a successful coating process, and began field testing the sensor in a King County stilling well and compared it with a commercial pressure transducer water-level recorder. The initial field testing was successful and the University began to look for a manufacturer.

The developers wanted to work with a manufacturer and distributor who believed, as they did, in the need to maintain quality while



The pod and the rod.
Photography courtesy Sequois Scientific, Inc.



Pod internals for data logging.
Photography courtesy Sequois Scientific, Inc.

keeping the price low. Negotiations were initiated and successfully completed with Sequoia Scientific, Inc., in Mercer Island, Washington.

Under a technology transfer agreement, product design information was licensed to Sequoia Scientific. Sequoia has transitioned the University's prototype into a manufacturable product. In addition to improving the inner rod coating and mechanical design, they improved the calibration technique such that accuracy is enhanced. The electronics, microprocessor programming, and interface software have also been upgraded to improve performance, reliability, and to utilize the new calibration procedure. The instrument, now called AquaRod, is part of Sequoia's standard product line.

The AquaRod is designed to measure water level in wells, streams, rivers, and lakes. The two-part instrument has a built-in data logger that attaches to the wand that serves as the capacitance gage. Each and is calibrated to correct the capacitance measurement at different temperatures, allowing water level, air temperature, and water temperature to be stored in the data logger. Wands are available in lengths of 0.5 to 2 meters.

The instrument is battery operated (2AA) and can be set to sample at time intervals that vary from 1 to 30 minutes in 1 minute steps. The AquaRod can be programmed to measure water level at present time intervals or, for extended use, to log the data only when the water level rises or falls in relation to a programmable threshold. Up to 9,500 measurements can be stored in non-volatile memory so that data remains if the battery power fails during operation.

Stored data are easily downloaded into a computer via a communication unit and associated software provided by Sequoia Scientific. The communication unit plugs into the pod and the computer's serial port.

The instrument, which includes the data logger and software, costs between $800 to $900 per unit depending on rod length.

Information about the AquaRod, including an Operator's Manual, is on the Sequois Scientific, Inc. Web Page at:
http://www.sequoiasci.com

Obtain additional information about the water-level sensor and other instrument development from:

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P.O. Box 352100
Seattle, WA 98195-2100
Telephone: (206) 685-7651
E-mail: sbolton@u.washington.edu

Technical information about the development of the water-level sensor is available in:
Read, B.W. 1996. Development of a Low Cost Water Level Sensor and Data Logger System. Master of Science thesis in Electrical Engineering, University of Washington.

The use of trade and company names is for the benefit of the reader. Such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of other that may be suitable.

Ask DOCTOR Hydro

Dear Doc Hydro: I can understand why the holes for a gravelometer are square if one wants to duplicate the functions of a sieve. However, for pebble counting purposes, wouldn't it be better to have round holes to prevent the particles from fitting through the squares diagonally? Furthermore, a gravelometer with round holes would be relatively easy to construct.

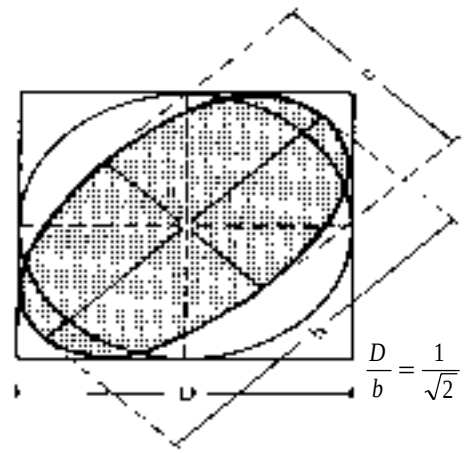
Round holed sieves in various configurations along with square sieves were considered when standards for particle size sieving were established. Round holed sieves were rejected in favor of the standard square wire-mesh sieves commonly used today. The relative ease of constructing wire mesh squares may have been a factor in the determination.

You are correct in your observation that round holes give an accurate measure of the intermediate axis (the b-axis), while intermediate diameters measured with the square holes of a gravelometer systematically produce smaller diameters than those measured with round holes, calipers, or rulers since particles can pass diagonally through the square hole but are tallied based on the size of the square. The difference in the results depends on the shape of the particle, with differences more pronounced for platy than spherical rocks.

The standard practice is to measure particles by considering the three mutually perpendicular axes (the largest a-axis, intermediate b-axis, and smallest c-axis). Correctly identifying the b-axis can be a problem and is a potential source of error. Unless calipers are used, measurements made with rulers can also introduce an additional degree of parallax error in measuring the b-axis. Templates are used to remove this observer error.

The main reason for square holed templates is to make field determined particle size distribution data comparable with particle size data analyzed with wire-mesh sieves. Comparing data is typically necessary since particles less than 2 mm in size are normally determined by conventional sieving, while larger particles greater than 2 mm are often manually measured. Using round hole templates would introduce an unnecessary complication in the comparability of field and sieve samples.

It is possible to correct for this discrepancy, which depends on the ratio of the c-axis to the b-axis as shown in the following diagram.



$$\frac{D}{b} = \frac{1}{\sqrt{2}}\left[1+\left(\frac{c}{b}\right)^2\right]^{1/2}$$

Adapted from: Church, McLean, & Wolcott, 1987. River Bed Gravels: Sampling and Analysis. In: Thorne, Bathurst, and Hey (editors), **Sediment Transport in Gravel-bed Rivers**, John Wiley & Sons Ltd., p. 51.

D is the template opening and b and c are the intermediate and smallest dimensions of a particle, respectively. D/b in the equation is the correction factor required to convert caliper measured b-axis to equivalent square template openings. Note that the c-axis must be measured to make the calculation.

Flooding, Land Use, and Watershed Response in the Blue Mountains of Oregon and Washington

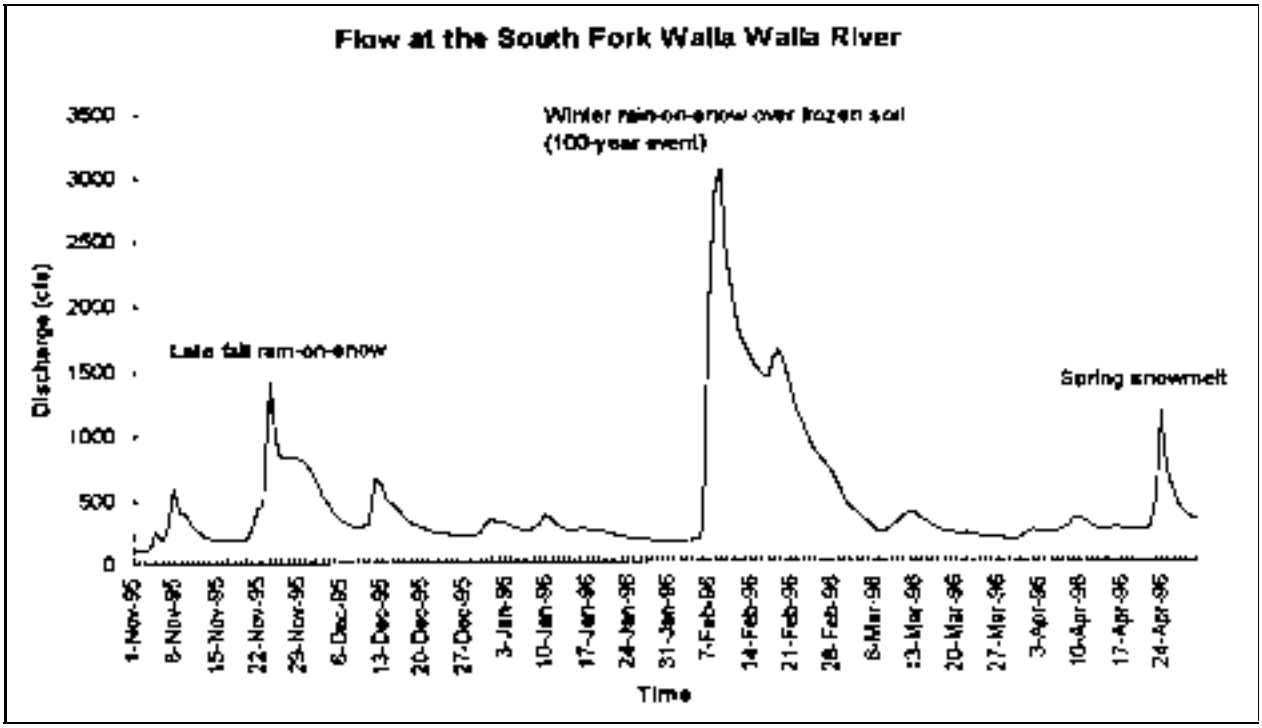
Jim Fitzgerald and Caty Clifton

The northern Blue Mountains sustained heavy rain and rapid snowmelt in November 1995 and rapid snowmelt over frozen soil in February 1996. The result was multiple record flood events, with the February peak flows being more widespread and of higher magnitude (see figure below).

The flood assessment focused on characterizing the events, inventorying mass wasting features, mapping channel perturbations, estimating flood magnitude and frequency, and evaluating the performance of instream fish habitat structures and stream-road crossing culverts.

In addition to flooding, the storms triggered debris flows and slides that commonly occurred in the rain-snow transition zone, in saturated loam-clay-ash soil, and on steep slopes (30 to 80%). Debris flows or torrents, the dominate feature, start as earthslides and sometimes transported debris over a distance of one mile. Roading and logging were associated with 37% of the observed mass wasting features.

High flows and mass wasting combined to produce a variety of channel responses including: scouring of substrate and banks, sediment aggradation, large woody debris accumulation, and lateral channel mitigation.



Flow of the South Fork Walla Walla River between November 1995 and April 1996. Causes of peak flows include: 1) late fall rain-on-snow, 2) winter rain-on-snow over frozen soil, and 3) spring snowmelt.

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Fluvial responses differed with elevation and land use intensity.

Flood discharge of National Forest streams was estimated using the indirect, slope-area method based on post-flood field evidence. Flood frequencies were estimated using U.S. Geological Survey regional flood equations. Flood magnitude and frequency varied by watershed with some areas experiencing one or more "100-year" events (Umatilla and Walla Walla) and others experiencing less than a "25-year" event (Tucannon and Wenaha).

Management Interactions

Instream Structures - Results from field inventories indicate a high rate (73%) of instream fish habitat structure survival. Survival rate varied between debris and coarse sediment caused the majority of culvert failures, rather than undersizing for flow.

Findings and Recommendations:

- a high rate of structural survival
- expect some structures to move or shift during high flow events
- design structures that work with fluvial processes, not against them
- limit use of "rigid" structures (e.g., cabled log-rock weirs)

Stream-Road Crossings - In roaded watersheds, a sample of culverts at stream-road crossings indicated that approximately 50% of the culverts failed. The failure rate varied by watershed. Culverts in the Umatilla River watershed had a 5% failure rate compared to those in the Tucannon River watershed, which experienced a 95% culvert failure rate. Results indicated that debris and coarse sediment caused the majority of culvert failures, rather than undersizing for flow.

Findings and Recommendations:

- expect culverts to plug with debris during large floods and design them to allow for overlapping
- design crossings to accommodate bedload carried by high flows
- assess upslope conditions to determine landslide and debris flow potential, and unit discharge
- use catchment basins at inlets to capture sediment and debris
- evaluate the benefits of decommissioning damaged sites relative to repair costs, assess needs, and downstream values

Conclusion

Forest investments, such as roads, hiking trails, and instream habitat structures, were damaged as a result of mass wasting, erosion, and channel migration. In addition, land use accelerated flood damage in some areas by decreasing slope and channel stability and potentially increasing flood magnitude. The post-flood assessments will be used to improve understanding of watershed response to extreme hydrologic events and to improve management practices to reduce damage from future high flows.

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A complete summary of this study, originally presented as a poster presentation at the Inland Northwest Water Resources Conference, Spokane, WA, April 28-29, 1997, is available from the authors.
To request a copy, phone or fax Caty Clifton at: Phone (541) 278-3822 or FAX: (541) 278-3730.

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