A Simple, Self–Contained Canal Stage Recorder

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Abstract. *Studies of surface water and shallow groundwater hydrology require intensive replicated measurements of water levels, preferably in computer–ready digital form. Commercial digital stage recorders are expensive, which prompted the design and construction of an inexpensive, automatic, digital canal stage recorder with off–the–shelf materials. This device fits into a PVC pipe used as a stilling well, making a sturdy design and very simple installation and maintenance. Step–by–step instructions on the recorder construction are presented as well as design considerations to fit a particular application. The field performance of the stage recorder was assessed in a canal in South Florida. Continuous water level readings were compared with those readings obtained at a stage recording station maintained by the South Florida Water Management District. Results obtained during the experimental period of 4.5 months showed good agreement between these two instruments ($R^2_{1:1}$ = 0.996 and y = 0.9524x + 0.048; R^2 = 0.998) and a measurement resolution of 0.63 cm when using an 8–bit data logger. The simple canal stage recorder could be adapted for measuring water levels in shallow wells, lakes, and tidal lagoons.*

Keywords. *Water level, Instrumentation, Hydrology, Canal stage, Recorder, Sensor.*

Recording water level in canals and other water bodies is a common task in hydrological research. Water level (stage) time series is the boundary condition determining the flow of water to and from drained lands. Moreover, if the cross–sectional area and velocity of the canal or watercourse is known, the stage level can be translated into series of flow rates vs. time or hydrographs. While many methods exist for measuring fluctuating free water surfaces, most of these use manual devices (Izuno et al., 1988, 1999; Hood et al., 1991; Smajstrla, 1997). Automatic devices that accurately log the behavior of water levels at relatively short time intervals are preferred for research purposes because they better capture the dynamics of the water body with time. However, the high cost of commercial digital stage recorders has restricted the widespread use of these automated methods in research. Many older stage recorders are still mechanical devices using graphical chart recorders, with no direct digital data storage (see Brakensiek et al., 1979 for a complete description). The recording and interpretation of such analog data is labor intensive and costly.

The purpose of this work is to present and evaluate a new design for automated digital measurement of water levels in canals and other water bodies. The design criteria chosen were simplicity, low cost (~$160 for materials), sturdiness, and ease of use.

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Materials and Methods

The proposed design is a float and pulley stage recorder automated by a half bridge excitation circuit and an inexpensive 8–bit datalogger. Similar float and pulley mechanisms are used in many older mechanical stage recorders (Brakensiek et al., 1979). An advantage of this mechanism is that it is not temperature sensitive like the ultrasonic transducers or pressure sensors used in some designs for measuring water levels. All components are housed inside the top of a PVC pipe "well" and covered with a PVC cap. Because there is no need for additional external wiring, the device is very simple to install and manage in the field. This design is a modification from an original design for a groundwater recorder developed at the University of Florida Citrus Research and Education Center (UF–CREC), Lake Alfred, Florida. It was modified at the University of Florida Tropical Research and Education Center (UF–TREC) for use in a canal, and to avoid the problem of the line sliding in the pulley.

All components and tools are readily obtainable "off the shelf" (tables 1 and 2, and fig. 1) with an approximate materials cost of $160, including the datalogger. The chosen datalogger (HOBO H08–006–04 datalogger, Onset Computer Corporation, Pocasset, Mass.) was inexpensive, flexible, reliable, easy to operate, and had a very low power consumption. A new 3V lithium battery should last at least nine months when logging at 15–min intervals. The datalogger's nonvolatile memory (32,768 bytes) was sufficient for continuously recording water levels at 15–min intervals, without downloading, for a year. The logger also had three additional analog ports to measure other environmental variables if needed. In this case, the total memory would be divided among recording devices reducing the maximum recording period available. The other electrical component in the design, a 10–turn wire wound potentiometer, was chosen for long life, moisture resistance and resolution.

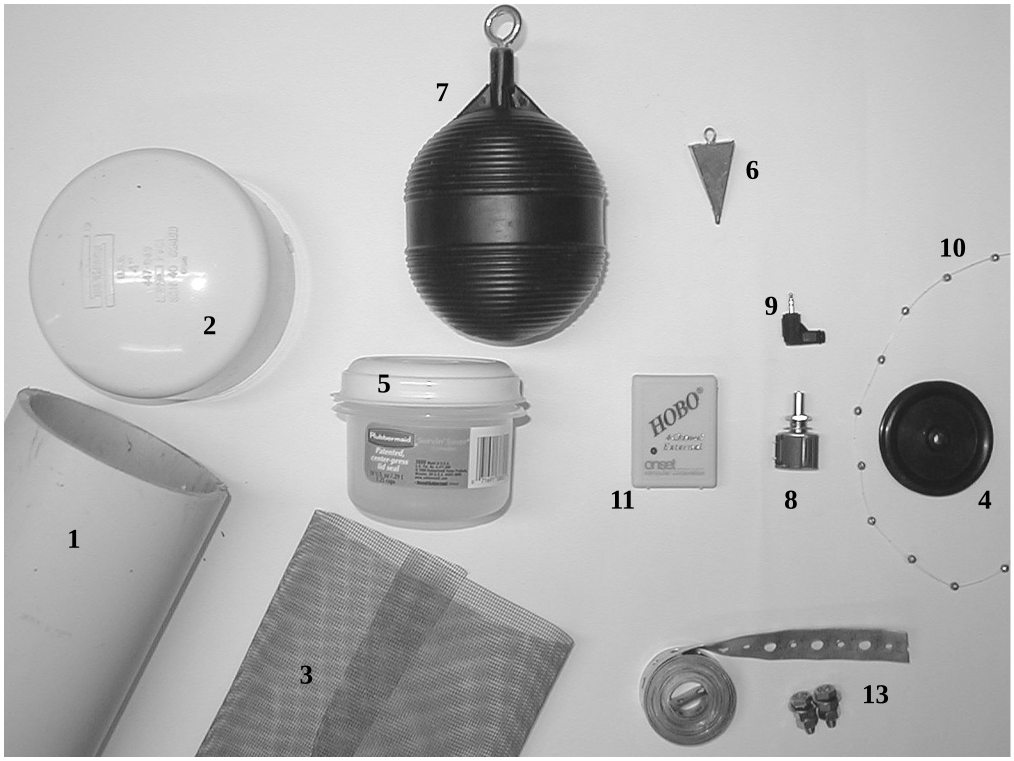

Figure 1. Materials used in the construction of the stage recorder. Numbers correspond to those given in table 1 (item 12 not pictured).

CONSTRUCTION

1. Perforate the lower 1.80 m of the PVC pipe (part 1, fig.1) with 10 to 20 25.4–mm (1–in.) diameter holes. If the spot to measure in the canal has significant water flow, perforate only the 1/4 to 1/3 of the pipe circumference opposite to the flow to increase the stilling effect. Insert the drain sleeve (part 3, fig. 1) to cover the 2–m perforated section. Drill one or two additional small holes close to the top of the pipe (30 cm) to ensure atmospheric pressure inside the pipe in the event that the water level rises above the lower 1.80 m. Close the bottom of the drain sleeve with a knot and secure the sleeve to the pipe with a loop of ~18 gauge wire.
2. Solder the connections of the mini–plug (part 9, fig.1) to the potentiometer (part 8, fig.1) as shown in figure 2 and use shrink tubing to cover the soldered connections. This cable with the potentiometer at one end and the mini–plug at the other will be used to plug into ports 1–4 of the datalogger (part 11, fig.1) when mounted (fig. 4).
3. Measure the diameter of the pulley (part 4, fig. 1) at the bottom of its groove with a caliper. From that measurement calculate the working circumference of the pulley and divide it into a whole number of segments (at least 5) so that segment length is about 30 to 40 mm. The working circumference may be directly measured without a caliper by wrapping and marking a single turn of fishing line on the pulley. Drill holes (BB shot diameter + 10%) in the pulley circumference equally spaced at exactly the length of the previously calculated segments. The split BB shots in the line will engage in the holes when the wheel turns to avoid sliding.
4. Measure the amount of line needed based on the expected change in water elevation. Note that the maximum length is related to the diameter of the pulley chosen. Using a 10–turn potentiometer, the range (R) of the device (the maximum change in water elevation it can handle) is defined as: $R = 10 \phi d$ (1) where d is the effective diameter of the wheel. Note that the counter–weight will obstruct the float if the pipe and/or line length is too short. If the expected water elevation fluctuation is unknown, use a line length equal to the well pipe length (3.04 m).
5. Prepare the line with the split BB shots equally spaced at the distance determined in step 3. A minimum of five holes are recommended for the pulley to ensure that at least three holes will engage with the BB shots on the line at any time. To fix the shots to the line, use a small drop of cyanoacrylate glue (“super glue”) and press gently with a pair of small pliers, noting that applying too much pressure will distort or flatten the shape of the shot so that it will not fit in the pulley holes (see part 10, fig.1).
6. Fill the float (part 7, fig.1) with sand or other ballast so that its final weight (e.g. 110 g) is slightly greater than the lead fishing sinker (part 6, fig.1) used as a counterweight (e.g. 93 g). Tie one end of the line to the float and the other end to the counterweight.
7. Mount the pulley on the potentiometer shaft and secure with cyanoacrylate glue. Note the float needs to be inserted before fixing the bracket with the bolts and nuts to the pipe. Mount all parts with the bracket (part 13, fig. 1) to the PVC pipe as shown in figures 3 and 4, making sure that adequate space is allowed to mount the plastic container and three supporting bolts. The three supporting bolts are mounted at about 120 degrees of the circle as seen

in figure 4 and are used to hold the plastic container above the pulley reach when closing the device. Enough space must be provided between these screws and the top of the pipe so that the plastic container can fit inside and the end cap can be placed on top. To obtain a consistent response, it is important for the potentiometer and line to be always at the same position. This setting can be achieved by winding up the potentiometer all the way (10 turns), and setting a predetermined BB shot at the end/beginning of the line in the top most hole of the pulley. Paint the BB shot with a permanent marker for future maintenance or service. To ensure that the potentiometer will always respond consistently on different devices, use a consistent convention for placement of the float and sinker over the pulley. We used a convention where the float was always placed to the right of the pulley, when viewing the potentiometer from the shaft side. If no prior knowledge of water elevation fluctuation is available, we recommend starting the device with the potentiometer set midway at five turns, assuming a mean annual water level and a range of ∂0.5R (fig. 5). Re–initialization may then be required later if the potentiometer runs out of range.

8. Cut a small incision in the top rim of the plastic container (part 5, fig.1) for the cable so that the lid, when closed, does not damage it. Place the logger and a desiccant bag in the container, close and insert it into the pipe in the space above the three screws mentioned before. Ensure that the excess cable is tucked into the container to avoid catching on the pulley mechanism. Close the top of the pipe with the PVC cap (part 2, fig.1) for protection.
9. The datalogger must be configured and started before field installation. The vendor provides a Windows⊇ based program for this purpose (table 1). For our field application, we configured the logger for voltage readings (0–2.5 V) in port 1 every 15 min. The logger start up can be delayed to a time after final field installation.

Table 1. Materials used and suggested sources for construction of the stage recorder.

No.	Item	Approx. Price (US$)
1	Sewer pipe: 3.05– Δ 0.102–m (10–ft Δ 4–in.) or 0.102–m (4–in.) PVC pipe	7.00
2	End cap: 0.102 m (4 in.)	3.00
3	Drain sleeve: 1.83 m Δ 0.102 m (6 ft Δ 4in.)	2.00
4	Utility plastic pulley: 50.8– to 76.2–mm (2– to 3–in.) outside diameter, 6.342–mm (1/4–in.) bore	5.00
5	Rubbermaid no. 6 round container (235 mL)	1.00
6	Lead fishing sinker used as counterweight: 85.2 g (3 oz)	0.50
7	Plastic toilet float	4.00
8	BOURNS 10k, 10–turn potentiometer, 6.342–mm (1/4–in.) shaft	14.00
9	Stereo sub–mini plug, 90–degree	2.00
10	Fishing line [~5.45 kg (12 lb) grade] and split BB shots	3.00
11	HOBO H8 four–channel indoor data logger (H08–006–04)	85.00
12	BoxCar 3.7 Starter Kit (software and cables for HOBO)	14.00
13	Other: mounting bracket; use 19.05–mm (3/4–in.) galvanized steel, 0.3–m (1–ft) three–wire insulated cable, 0.102–m (4–in.) shrink tubing, nuts and bolts, silica gel desiccant pack, ~18 gauge wire to secure drain sleeve, cyanoacrylate glue (“super glue”).	10.00 10.00
Total		160.50

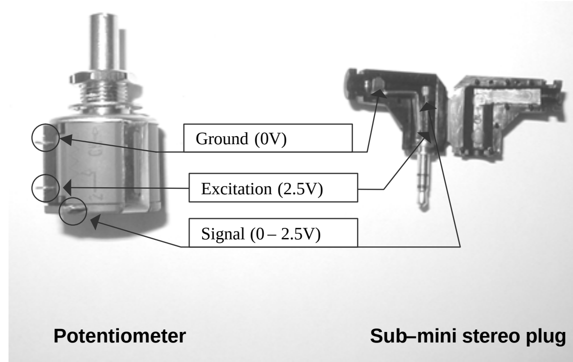

Figure 2. Terminals of the potentiometer and plug to connect by soldering cable ends.

FIELD INSTALLATION

The instrument needs to be secured with brackets to a stable structure. If the device is attached to a platform, it should not be a floating platform but rather one supported at the canal bank and/or with foundations at the bottom so that no changes in elevation are possible.

Typically, a topographical or laser level survey is needed to relate the elevation of the top of the pipe (or other measurement reference such as bridge/platform where the device is mounted) to a reference elevation nearby to be able to compare the readings with external data.

After initial installation a manual measurement of the water level (distance from top of the pipe) is needed. It will be used to convert the signal stored in the logger (voltage) to the true elevation [mean sea level (msl)].

OPERATION OF THE DEVICE

Normally, no special maintenance is needed except cleaning of weeds and debris in the water around the PVC pipe. Application of silicone grease to the potentiometer

Figure 3. Potentiometer and pulley attached to mounting bracket, ready for bolting into the well housing after making the solder connections. The roll of galvanized steel strap illustrates the material used to fabricate the bracket.

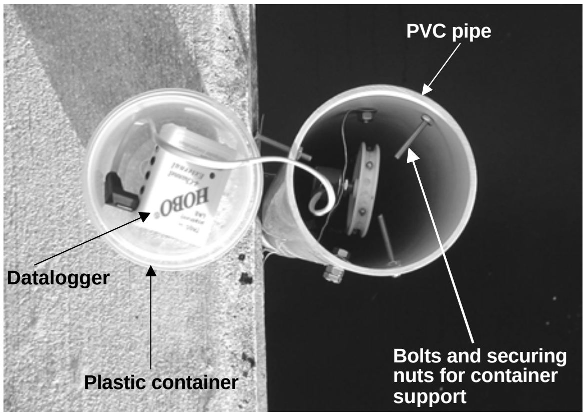

Figure 4. Detailed view of the instrument showing the pulley bracket mounted inside the pipe and the connection to the datalogger.

shaft is recommended to combat corrosion. To download data, refer to the datalogger instructions. If the device needs to be removed for any reason, care should be given to set the line and potentiometer on the original position when re–installing it (see step 7 in the Construction section).

To convert the raw data (voltage) to water elevation, a point on the time series has to be known in terms of the true water level. It is important that manual readings from the top of the pipe to the water level are taken each time the data is downloaded. This way, a starting and end point are known in the series. These known values should be compared to processed data from the logger (described in the following section) to ensure data consistency during a prolonged experimental period. Since data is recorded every 15 min, for applications where minimum error is required, real–time data can be obtained from the logger with a handheld PC at the time of the manual reading.

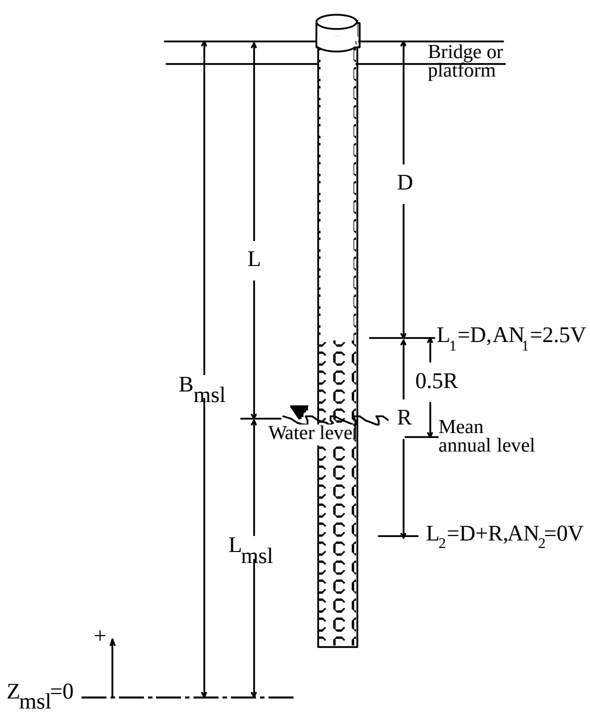

Figure 5. Dimensions used to calculate the water level in the canal with the stage recorder (see Nomenclature section and text for explanation of abbreviations used).

Data Processing

The conversion of the raw data is made by knowing the sensor range (eq. 1) and shifting the series up or down to match the known water levels. The water elevation (L, measured from the top of the platform or bridge) that the device can register will vary between D and D+R, with R the range given in equation 1 (fig. 5). For the upper boundary, the analog signal (AN) registered in the logger will be 2.5V and for the lower one 0V (L_1 and L_2 in fig. 5, respectively). Then,

$$L = D - R/2.5\,(AN - 2.5) \qquad (2)$$

If at a given time we know the water elevation (L_o), measured manually, and the equivalent signal (AN_o) we can substitute in equation 2 to obtain the value of D,

$$L_o = D - R/2.5(AN_o - 2.5) \Downarrow D = L_o + R/2.5(AN_o - 2.5) \qquad (3)$$

With this value equation 2 now becomes,

$$L = L_o + (R / 2.5)(AN_o - AN) \qquad (4)$$

If a reference elevation value (msl) at the top of the bridge or platform is known from a topographical survey (B_{msl}) then the water elevation can be referenced to msl with equation 5,

$$L_{msl} = B_{msl} - L_o - (R / 2.5)(AN_o - AN) \qquad (5)$$

The resolution error (E_r) or accuracy of the 8–bit logger is (Kimber, 1994),

$$E_r = R / (2^8 - 1) = R / 255 \qquad (6)$$

Additional errors in the device may result from the engaging of the line with the pulley, typically in the order of 0.5 cm and usually less than 1 cm.

Results and Discussion

Application Case Study

A device was installed on a bridge at the C–103 canal near UF–TREC Homestead (Fla.) on February 2002. A topographical survey was made and showed that at the side of the bridge, B_{msl} = 424.3 cm NGVD29 (National Geodetic Vertical Datum of 1929). The wheel of the device had a diameter d = 5.08 cm (2 in.), which yielded a range R = 159.6 cm (eq. 1). After installation, the water level was measured from the side of the bridge with a tape mounted on a long metal stick giving a distance of L_o = 307.0 cm while the logger registered AN_o = 1.196 V. Two weeks later the data were downloaded and the water level measured manually again (L = 338 cm) while the logger registered 0.718 V. The measuring error (E_m) of the device can be calculated using equation 4 and the last registered voltage value. The calculated water elevation and errors in this case were,

$L = 307.0 + (159.6/2.5)(1.196 - 0.718) = 337.5$ cm
$E_m = 338 - 337.5 = 0.5$ cm
$E_r = 159.6/255 = 0.63$ cm $\approx E_m$

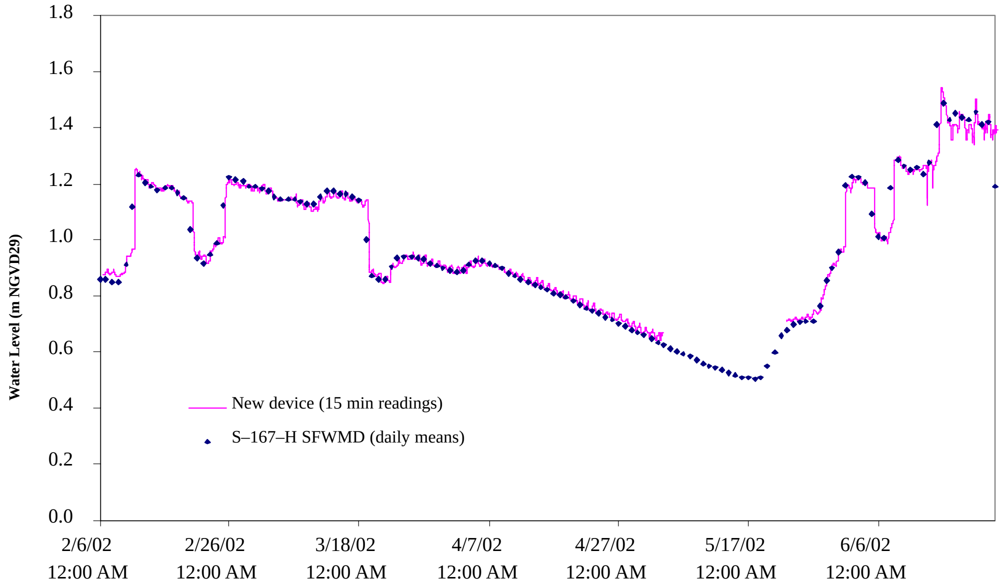

Figure 6. Comparison of canal stage hydrographs measured with the stage recorder and data from a nearby South Florida Water Management District automated canal structure

The msl values at the beginning and end of the two–week period were 117.3 and 86.8 cm NGVD29, respectively.

A 4.5–month data series obtained with the device is shown in figure 6. On 8 May, while downloading data and cleaning the device, the line was accidentally taken out of the pulley. This error was corrected three weeks later. A comparison is made with mean daily values obtained in the same canal about 3 miles downstream, at the headwater of the S–167H structure operated by the South Florida Water Management District (SFWMD) (symbols in fig. 6). The hydrology of the canal system is such that very little elevation difference is expected between the two canal locations. Note that the low–cost device is more sensitive to water changes since it is programmed to read every 15 minutes (96 readings a day), in comparison to a daily average recorded at the S–167H structure.

In order to statistically compare both devices the data series obtained with the new device was transformed into mean daily stages for the period. The paired series is plotted against the 1:1 line (line of perfect agreement) in figure 7. The small scattering observed is likely due to the different intervals of sampling between the two devices as well as the distance in the canal (3 miles), which could cause differences due to wind and other local effects.

Several statistics provide measures of likeness between hydrographs. These methods have been developed to compare measured vs. predicted hydrographs, usually from modeling exercises (Aitken, 1973; James and Burges, 1982; McCuen and Snyder, 1975). A first approximation of the error in the comparison can be obtained from the mean square error (MSE) and the root mean square error (RMSE) (James and Burges, 1986). One simple statistic available is the R–squared of the values against the 1:1 line ($R^2_{1:1}$), with perfect agreement when the value is 1. Other authors (Aitken, 1973; McCuen and Snyder, 1975) discuss that it is possible to obtain high $R^2_{1:1}$ values without actually following the trend properly. This is the case when errors, under or over compensate for each other, such as when the response of one of the series shifts in time with respect to the other. They present alternative statistics that include mass (or area under the curve) as well as serial correlation. Two of such statistics are used here: the Pearson weighted moment (PWM) and the Pearson moment square (PMS) (McCuen and Snyder, 1975). Both statistics are R–square types (1 is the optimal value). Finally a paired t–test was conducted to assess if there was a significant difference in the means, with the null hypotheses that the means were equal. Results from these tests are summarized in table 3. All values confirm that the agreement between the reference data set (SFWMD station) and the inexpensive device presented here is excellent.

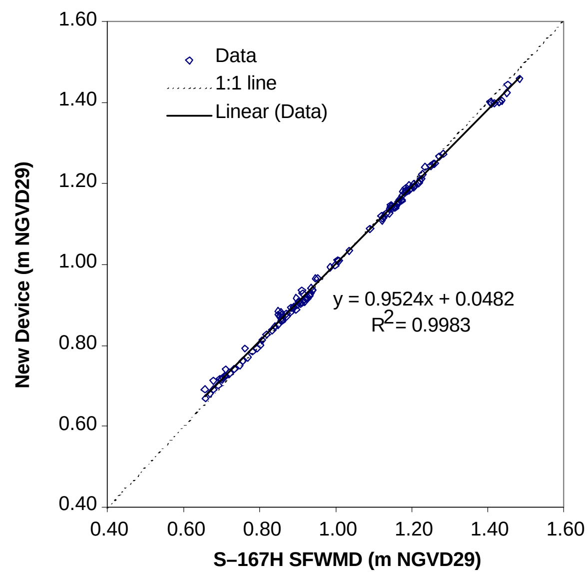

Figure 7. Correlation between the mean daily water elevation values obtained by the new stage recorder and the reference station.

Table 2. Tools and equipment needed in the construction of the device.

Item
Soldering iron and solder
Power drill and bit set
Pliers
Caliper
Adjustable wrench
Screwdriver

CONCLUSIONS

A simple, inexpensive (around $160 materials cost) canal stage recorder is presented. The compact, self–contained design (stilling well, float and pulley mechanism, datalogger all in one 4–in. pipe) makes it very sturdy for continuous field operation. The off–the–shelf inexpensive datalogger chosen in the design is flexible, reliable, and easy to operate. The stage recorder proved very simple and reliable to record canal levels in South Florida during 4 1/2 months of continuous use. The maximum measurement resolution of <0.5 cm is sufficient for most hydrological research. It could be further improved, although at a higher cost, by substituting a 10– or 12–bit datalogger for the 8–bit device used here. The stage recorder can also be used to measure groundwater fluctuations in irrigation wells or to monitor lake or lagoon level changes.

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Table 3. Summary of statistics calculated to compare the water level readings of the constructed stage recorder with a reference stage recorder (S–167H).[a]

$R^2_{1:1}$	PMS[b]	PWM[c]	t–Student	MSE[d]	RMSE[e]
0.996	0.998	0.952	0.059 (P = 0.953)	0.00018	0.013

[a] n = 118 mean daily values.
[b] Pearson moment square.
[c] Pearson weighted moment.
[d] mean square error.
[e] root mean square error.

REFERENCES

Aitken, A. P. 1973. Assessing systematic errors in rainfall–runoff models. *J. of Hydrology* 20(2): 121–136.

Brakensiek, D. L., H. B. Osborn, and W. J. Rawls (coord.). 1979. Field manual for research in agricultural hydrology. Agricultural Handbook No. 224, 132–170. Washington D.C.: USDA

Hood, C. F., A. G. Smajstrla, and F. S. Zazueta. 1991. Measuring water levels in wells: An inexpensive electric water level indicator. Fact Sheet EES–62, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Fla.

Izuno, F. T., D. Z. Haman, and G. A. Clark. 1988. Water table monitoring. Bulletin No. 251. Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Fla.

Izuno, F. T., G. A. Clark, D. Z. Haman, A. G. Smajstrla, and D. J. Pitts. 1999. Manual monitoring of farm water tables. Circular 731. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Fla.

James, L. D., and S. J. Burges. 1982. Selection, calibration, and testing of hydrologic models by. In *Hydrologic Modeling of Small Watersheds*, eds. C. T. Haan, H. P. Johnson, and D. L. Brakensiek, Chapter 11, 435–472. St. Joseph, Mich.: ASAE.

Kimber, W. A. 1994. *Practical Digital Electronics for Technicians*. Oxford: B–H Newnes.

McCuen, R. H., and W. M. Snyder. 1975. A proposed index for comparing hydrographs. *Water Resour. Res.* (AGU) 11(6): 1021–1024.

Smajstrla, A. G. 1997. Simple water level indicator for seepage irrigation. Circular 1188, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Fla.

NOMENCLATURE

R	Range (R) of the device (the maximum change in water elevation it can handle)
D	The effective diameter of the pulley wheel
msl	Mean sea level elevation
L	Water elevation measured from the top of the platform or bridge
D	Upper boundary of the device's water level range
AN	Analog signal registered in the logger (0–2.5VDC)
L_o	Water elevation known (measured manually) at a given time
AN_o	Equivalent analog reading at L_o
B_{msl}	Reference elevation value (msl) at the top of the bridge or platform known from a topographical survey
L_{msl}	Water elevation measured referenced to msl from the top of the platform or bridge
Z_{msl}	Origin plane of the msl, positive upwards
E_r	Resolution error or accuracy of the logger
E_m	Measuring error with a reference reading