Irrigation Flow Measurement with a New Metering Pipe System

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INTRODUCTION

The California Water Conservation Act (Senate Bill SBx7-7) was passed in 2009. The Farm Irrigation portion of the law is targeted to be implemented by July 31, 2012. At that time all applicable Water Districts are requested to supply the State with their long range plan to meter the volumetric flows into the Farm turn-outs and establish that they have implemented initial physical measures to record the volumes of water that they bill to the Farmers. The accuracy specifications of the measurements varies, with some applications acceptable if between ±5% to ±12%.

Value of water measurement knowledge: Metering the farm deliveries offers significant advantages to both the farm and delivery canal operations. Accurate flow rate indications help the canal operator to distribute the canal delivery among several users more competently. This stabilizes the canal and provides steady delivery to the farm operations, allowing the farm operator more control to optimize on-farm water-use. The value of flow measurement information to irrigated agriculture is briefly discussed in Appendix I (The Case for Flow Measurement).

Limitations of "Spot" Measurements: The discussion of spot measurements used in an attempt to achieve annual delivery information, and why we discourage the process, is discussed in Appendix II (Problems with "Point-in-Time" Spot Flow Measurements).

APPLICABLE MEASUREMENT SYSTEMS

We examined many commercially offered systems in terms of (a) *accuracy*, (b) *economics*, and (c) *convenience*. Most systems, Ultrasonic, Venturi, Orifice, Weirs and Flumes, and intermittent insertion-sampling devices, had difficulty meeting all three criteria. We eventually selected for development a commercially available, reverse-propeller meter, inserted into a pipe, with added appurtenances, to prevent weed fouling, and to condition the flow profile. The system provided an electronic output that indicated flow rate and volume delivery for annual accounting, and can be upgraded to include supervisory control or automation.

Site conversion: The developed system adhered to the philosophy that often the most effective measuring technique is to convert the site to, as mathematicians would say, "a previously known solution." A simple conversion starts with adding a pipe to the outlet end of the existing field structure. This addition usually does not require changing the irrigation delivery structure itself and is expected to cause minimal invasion of the farm field. Figure 1 illustrates one such solution by adding an HDPE pipe to the existing outlet that is turned to parallel the road-field boundary. An additional "known solution," a reverse propeller meter, then detects the flow velocity in the pipe for determining volumetric delivery. The pipe is equipped with newly developed appurtenances to condition the flow from a gate jet or pipe elbow for accurate velocity detection with the time-tested, reverse-propeller meter, and to bypass weeds and grass.

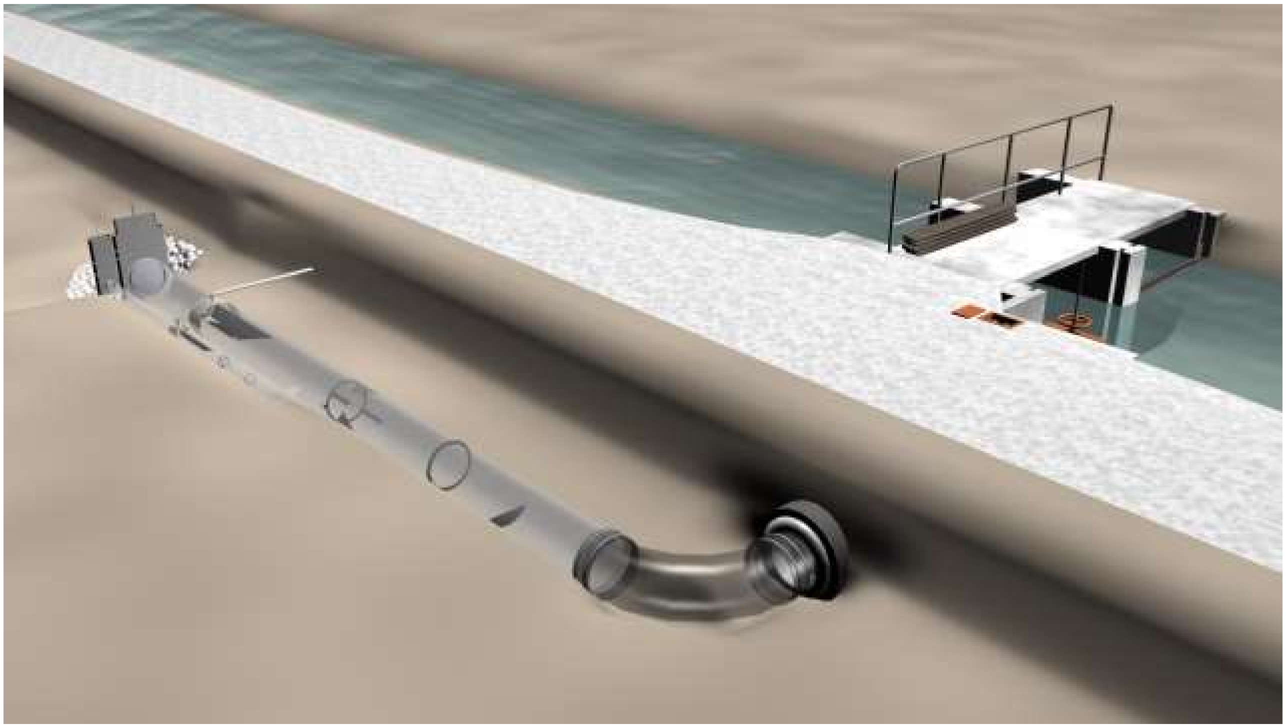

Figure 1. One of many configurations for field application

Flow Conditioning and Weed shedding: The conventional wisdom is that propeller meters, even reverse propeller meters, are severely challenged by the vegetative growth that occurs in open channel flow canal systems similar to that of the Imperial Irrigation System (IID). Many, if not most, of the farm-irrigation, water-delivery systems in California Irrigation Districts deliver water through a pipe placed through the canal bank, frequently under a canal service road. The pipes are usually 20-feet to 40-feet long. The opening and closing of a canal head gate, or sluice gate, usually controls the water delivery rate. This partly open sluice gate produces a strong jet into the pipe that can cause a distorted flow profile and flow spinning that greatly affects most efforts to sense an average velocity in the available length of pipe. To achieve both velocity-profile conditioning and control of flow spin, we introduced special flow conditioning measures between the entrance gate and the propeller meter that controlled both, and produced the desired uniform-flow profile for the propeller, or most any sensor, to detect average velocity. This system could be installed in most locations where the farm deliveries were through a pipe in the canal bank, or any location where a suitable section of pipe could be installed. This could even be placed in the beginning of a farm ditch and subsequently used as a culvert crossing by the farm operator. The ability to use the existing control gate at the delivery site is a low-cost measure and does not require changing the basic system to add any additional mechanized elements.

The hydraulic features included a weir-like blade about ¼ pipe diameter high placed a couple of diameters down the pipe to diffuse the jet energy across the pipe. Further downstream in the pipe was a large opening orifice (about 90% open area). That prevented jetting down the pipe wall and forced cross missing of the flow. A second orifice, this one preceded immediately with anti-spin vanes that resemble “shark-fins” protruding from the pipe walls, is positioned further along the pipe. Their purpose is to prevent flow spin and to further contribute to a uniform velocity profile. The weed and grass handling feature consists of a long vane attached to the inside pipe top that pushes weeds and grass down below the propeller blades. Smaller side fins push the weeds sideways around the meter. A weed-free zone thus exists for the operation of the reverse propeller meter.

The effectiveness of the weed shedding measures is illustrated in Figure 2, which shows the problem before we implemented the appurtenances in the system, and the subsequent successful performance for the remainder of the irrigation season.

Figure 2. Before (left) and after (right) adding the weed-shedding vane system.

Rice Culture. Most field-crop managers request a similar flow-rate delivery to their fields throughout the growing season. An exception is rice cultivation. Initially after planting, the grower requires a large flow rate to fill the rice field. Subsequently, the grower needs a much small maintenance flow rate for the remainder of the season. This maintenance flow rate amounts to about ¼ inch per day. The ratio of the large to small flow rate may be more than 20:1. To assure the delivery of large flow rates to quickly field large basins, we offer a dual metering system that can accurately measure a wide range in flow rates. This system is illustrated in Figure 3 with a typical 24-inch pipe and a parallel, but similarly equipped 6-inch pipe.

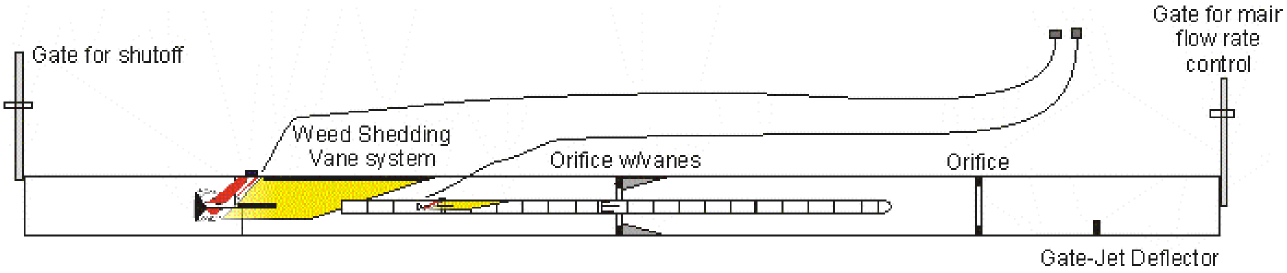

Figure 3. Basic components for a high flow rate and low maintenance flow rate to accommodate rice culture.

The system can be tailored to fit many field situations. It can measure large flow rates, small flow rates, and operate with small head differences between the delivery canal and the field water surface.

Table 1 lists the most commonly available pipe sizes in terms of inside pipe diameter. It also lists the estimated pipe system losses to expect. Thus, if the head difference is small and the desired delivery rate is high, the table will suggest a large pipe. Table 1 also suggests that the pipe velocity be maintained above about 3 feet per second to discourage sedimentation. This may not be practical for small head differences requiring large pipes. However, these situations frequently have water with low suspended sediment loads and can usually be made to work.

Table 1.

CANAL REVERSE-PROPELLER WATER METERING SYSTEM

For pipe sizes 16-ir to 30 -inch I.D.

Size in	Q cfs	Q gpm	velocity ft/s	V^2/2g inches	Headloss in.
30^A	30	13464	7.55	10.62	27.34
	25	11221	5.1	4.836	12.33
	23	10323	4.68	4.092	10.40
	20	8977	4.07	3.096	**7.87****
	15	6732	**3.1 ***	1.74	4.41
	10	4488	2.52	1.1796	3.06
	5	2244	1.258	0.295	0.77
27^A	25	11221	6.29	7.38	18.77
	20	8977	5.03	4.716	12.02
	17.5	7855	4.4	3.612	9.21
	15	6732	3.8	2.652	**6.77****
	12.5	5610	**3.14***	1.848	4.71
	10	4488	2.52	1.1796	3.02
	5	2244	1.26	0.2952	0.76
24^A	25	11221	7.96	11.82	30.07
	20	8977	6.4	7.56	19.27
	15	6732	4,77	4.248	10.86
	12	5386	3.82	0.227	**6.96****
	10	4488	**3.1***	1.896	4.82
	5	2244	1.59	1.896	2.29
22.44^A	20	8977	7.28	9.888	24.42
	15	6732	5.46	5.544	13.74
	13	5835	4.73	4.176	10.33
	12	5386	4.37	3.564	8.81
	11	4937	4.01	2.988	**7.40****
	10	4488	3.64	2.472	6.12
	9	4039	3.28	2.004	4.96
	8.5	3815	**3.09***	1.788	4.43
	5	2244	1.82	0.618	1.53
	3	1346	1.09	0.2232	0.56
21*	15	6732	6.24	0.605	15.60
	12	5386	4.99	0.387	12.39
	10	4488	4.16	0.269	10.27
	8	3591	3.33	0.172	8.17**
	6	2693	2.49	0.097	6.10
	5	2244	2.08	0.067	5.07
	4	1795	1.66	0.043	4.04
	3	1346	1.25	0.024	3.02
16^A	10	4488	7.16	9.564	24.67
	8	3591	5.73	4.032	14.25
	6	2693	4.3	3.444	8.91
	5.5	2469	3.94	2.892	**7.50****
	5	2244	3.58	2.388	6.21
	4.5	2020	**3.22***	1.98	5.06
	4	1795	2.86	1.536	3.97
	2	898	1.4	0.384	1.00

For pipe sizes 4-inch to 12-inch I.D.

Size in	Q cfs	Q gpm	velocity ft/s	V^2/2g inches	Headloss in.
12" max	5.57	2500	10.21	19.45	35.34
	5.00	2244	6.36	7.56	21.25
	4.00	1795	5.09	4.84	13.62
12	3.00	1346	3.82	2.72	**7.67****
	2.75	1234	**3.50***	2.29	6.46
	2.00	898	2.55	1.21	3.43
	0.50	224	0.635	0.08	0.22
12" min	0.334	150	0.426	0.03	0.09
10" max	4.01	1800	7.35	10.08	30.82
	4.00	1795	7.33	10.03	30.67
	3.00	1346	5.50	5.64	17.20
10	2.00	898	3.67	2.51	**7.71****
	1.75	785	**3.20***	1.92	5.90
	1.50	673	2.75	1.41	4.34
10" min	0.279	125	0.51	0.00	0.11
8" max	3.340	1500	9.57	17.10	29.28
	2.230	1000	6.38	7.60	24.47
	1.559	700	4.47	4.86	13.33
	1.225	550	3.51	2.292	**7.43****
8	1.114	500	**3.19***	1.90	6.16
	0.668	300	1.91	0.68	2.23
	0.446	200	1.28	0.30	1.01
8" min	0.223	100	0.64	0.08	0.25
6" max	2.675	1200	13.62	34.62	123.08
	1.114	500	5.67	6.01	21.47
	0.891	400	4.53	3.84	13.77
6	0.668	300	**3.40***	2.16	**7.78****
	0.446	200	2.27	0.96	3.48
	0.223	100	1.135	0.24	0.89
6" min	0.201	90	1.021	0.19	0.72
4" max	1.337	600	15.32	43.80	156.85
	1.114	500	12.76	30.41	124.21
	0.668	300	7.659	10.94	44.93
4	0.446	200	5.107	4.87	20.09
	0.290	130	3.32	2.05	8.55
	0.2785	120	**3.06***	1.75	**7.31****
	0.223	100	2.55	1.22	5.10
4" min	0.111	50	1.28	0.30	1.31

3.0* --Suggested minimum velocity
to discourage sedimentation
7.0** --Suggested minimum headloss
to be provided
30^A Max imun and minimum flow rates not listed..

Appendix I

The Case for Flow Measurement

--Worldwide, about 70 % of the water diverted from streams is used for irrigation.

According to Stockle (2001), irrigation allows land to be, on average, twice as productive as rain fed land. Even though only 16% of the world's croplands are irrigated, those irrigated crops produce 36% of the world's food (World Food Summit, 1996).

--The world will in a few years face a food shortage on a vast scale. Most of the increased food will likely come from improved crops grown under well managed irrigation applications.

--Managing irrigation water adequately requires knowledgeable farm operators and measurement of applied water. Thus, water measurement and education should go hand-in-hand.

--Water measurement assists in achieving uniform depth of water to the crop as well as assure adequacy application amounts. This can improve total yields significantly.

--Uniform water application may or may not decrease the total water volume applied, but the applied water can significantly improve average yields. A 5% to 10% average yield increase can mean $15 to $30, or more, increased income per acre per year (at least in the US). For every 100 acres, the cost of metering should be a net benefit to the farm operators. Larger units should find it even more beneficial.

--in most instances, improving application uniformity does result in reduced water application needs, because poor uniformity is too frequently remedied by increasing the applied amount to the field, much of which goes to deep percolation, well in excess of any leaching requirement.

-- For surface irrigation, there are many ways to improve uniformity:

-For level basins, increase application flow rate, but decrease the application time to compensate

-For sloping borders, carefully measured application rates to field slope, crop root zone, and soil-water intake rates. (Computer models are available.)

-For sloping borders, change the border width to bring needed application rate to within district capabilities to accommodate.

- For level basins, low available deliveries may make it desirable to either reduce the basin sizes (level borders) or reduce the length of run (shorter borders).

-In any case, to benefit from the computer models available that can improve uniformity, knowledge of the flow rate is an essential tool.

Appendix II

Problems with "Point-In-Time" Spot Flow Measurements

It has come to my personal attention that others are proposing to meet the requirements of the California Water Conservation Act (Senate Bill SBx7-7) as passed in 2009, by inserting a meter (propeller or other) into the discharge stream one or more times during the delivery for a point-in time value to meet the accuracy requirements. I strongly recommend that point-in-time methodology be rejected for the following reasons.

For the required accuracy to happen, several conditions may be necessary. These are:
--A relatively high difference, suggested to be at least two feet, should exist between the water surface levels of the delivery canal and that of the farm ditch.
--The delivery-canal water surface level should not vary more than four inches (16%) at any time during the delivery. Because of the "square-root" nature of most delivery points, this translates to about 8% discharge error.
--The farm-ditch surface level also should not vary more than four inches (16%) during delivery. This often occurs when irrigating various border-strips, some near the delivery entrance and some at distance.

If both water-surface fluctuations occur simultaneously at inopportune times then the errors can approach 16%. If the water-surface level difference is smaller, or if the fluctuations in water levels are larger, then these errors will be further exaggerated.

To illustrate the errors that point-in-time measurements can generate, I am presenting some actual field meter recordings of complete irrigation deliveries. These will illustrate the potential billing errors that can result if point-in-time records are used. Referring to Figure A, the delivered volume is about 19.6 acre-feet. This calculates to require an average reading of about 10.2 cfs for 24 hours. It would simply be fortuitous for two, or even three, point-in-time readings to average 10.2 cfs.

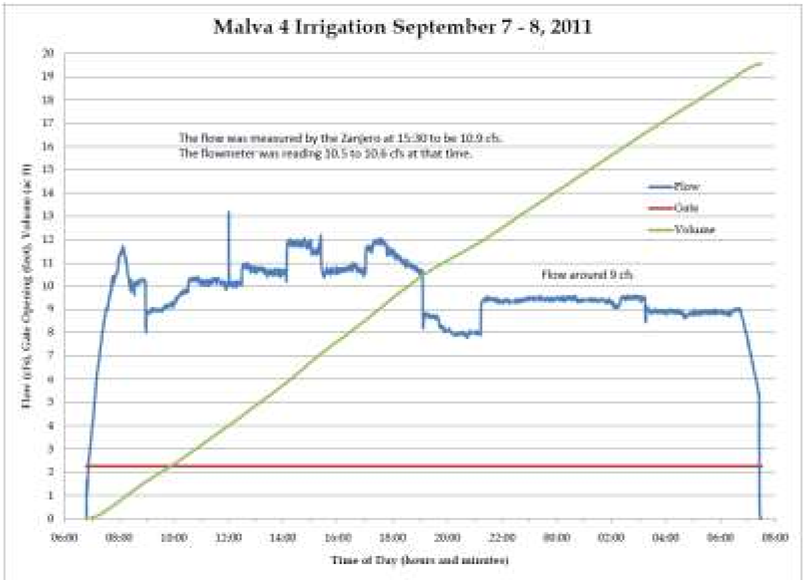

Figure A

A second recorded example is presented in Figure B. Again, determining the volume delivery from a few point-in-time measurements is very problematic.

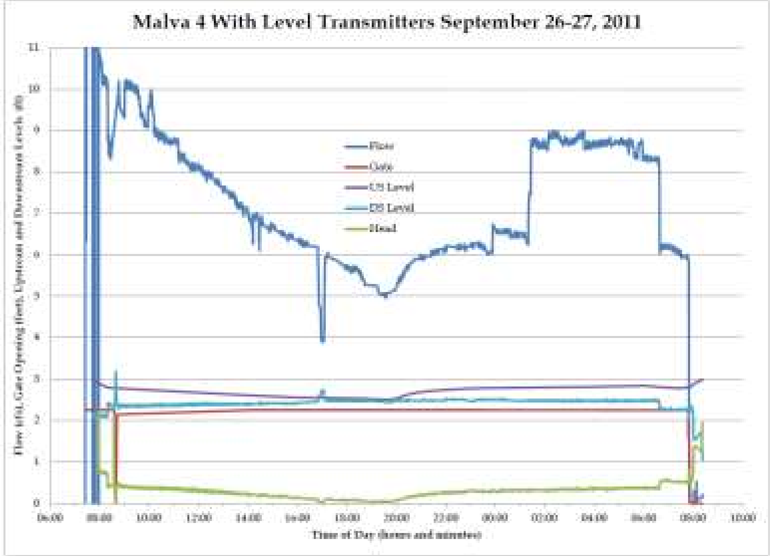

Figure B

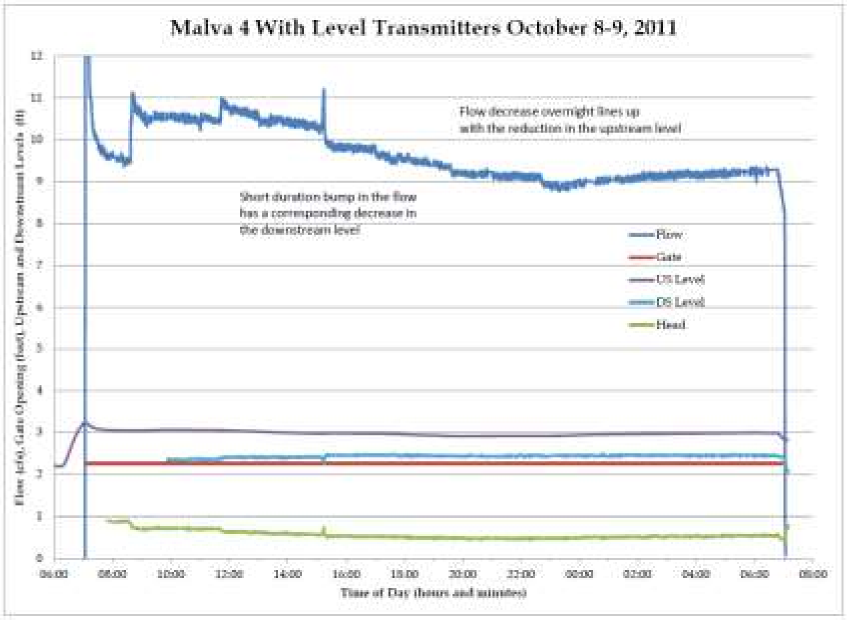

Figure C

Figure C does show enough regularity that it may be possible to meet the required accuracy. However, a reliable method to identifying excellent delivery situations in advance is not usually available.

DRAFT #2 16 May 2012
Ad hoc Canal flow measurements.

Decades of experience in measuring flow rates from canals to farm fields lead to the following observations:

FOR ORIFICE GATE EMPLOYMENT

1. **Difficulty and costliness of site calibration:** While a tumbling bullet hole in a bucket can be calibrated as an orifice meter, it would be a unique calibration and could not be generalized to other buckets. Thus, each bucket requires calibration. The advantage of drilling a clean hole is obvious. Canal delivery gate are likely to more resemble the bullet hole rather than the neatly drilled version.

2. **Shortcomings of spot measurements**: For decades, canal gates have been used to estimate flow deliveries based on orifice behavior. Most can be suitably calibrated for flow rate and are manually read once or several times per delivery. ***Accurate flow-volume information depends on multiple readings during the delivery and may involve significant office-staff follow-up for processing to volume information.*** Information usable to the farm operator may sometimes be available but usually is not timely or is inconvenient to obtain. The most frequent information is based on the flow rate ordered and the assumption that the system responds correctly. It may not be updated during the delivery even though many investigations have shown that significant delivery variations occur and often the canal operator is continually making gate adjustments in attempts to keep the delivery on track.

3. **Inconvenience of recording and using spot measurements:** Recording the differential head through a sluice gate and later converting the results to obtain a volume delivery through a particular farm delivery gate has been done on one-at-a-time basis. No consistent cost basis has been established. Usually special recording equipment and a computer has been used. In addition, office-staff time is usually involved, adding to the real cost of obtaining a monthly/annual volume delivery.

4. Use of the measurement by the Farm Operator: The output is sometimes available to the farm operator, but often is convoluted and not easily available.

5. Maintenance: Frequent problems with maintenance are common, requiring computer and electronic technician attention that overshadow the system cost of operation.

6. **Head Measurements**: Orifice readings themselves are more forgiving of error than weirs in that a 10% reading error in head is about equal to 5% error in discharge rate, assuming a correct calibration relation exists for the particular structure. Movable gates used as orifices are sensitive to direct error in determining the gate opening, that is, 10% error in opening is equal to 10% error in flow rate. Thus, without careful calibration of the site for many gate openings and the reliable ability to reproduce the gate opening, orifice gates measurements can be expected to be challenged to remain within +/-12% of accuracy.

WEIR-BOX SYSTEMS

1. **Weir Box Considerations:** Weirs can provide accurate discharge measurements when they can be operated in their optimum flow range. However, errors in head readings are exaggerated when determining discharge rates. A 10% head reading error is approximately a 15% discharge rate error for rectangular weirs and 25% error for triangular weirs. Thus, flow depths of less than 3-inches may have difficulty when sensing rectangular weirs with pressure transducers that usually are +/-1/8 inch, (4%) resulting in expected uncertainty of +/-6%, plus any site errors, including undetected head reading offsets. Site setup and head reading registration require special attention are easily damaged and misadjusted by vandals and wildlife.

2. **Flow Range Limits:** The "turndown" (ratio of high to low flow rates) is largest for triangular weirs, but they are usually limited to about 4 cfs. Thus, rectangular weirs are needed for high flow rates, but then low flows, such as needed for rice culture for maintenance flows, are inaccurately measured.

3. **Location Selection Limitations:** The required head drop severely limits the locations in a canal system where they can be applied. The vertical setting for weirs requires special engineering attention to achieve free discharge and still require minimum head. Minimum head is usually stated as the maximum expected head reading plus 2 inches. Special attention is needed to assure that proper overflow aeration occurs. They are most easily used in mountainous areas. Applications in flatter irrigated areas are difficult.

4. **Data Handling Inconveniences:** The conversion of head readings to volume records can be expensive, particularly if each site must have special attention.

CONCLUSIONS

1. **Up Front, Calibration, and Operational Costs:** The cost of individual orifice gate calibration of outlets for questionable sites is a valid concern. Accurate and widely applicable calibration procedures are usually tedious and require specialized technical knowledge.

2. **Costs of Retrofitting:** The cost of retrofitting a differential-head device (existing canal gate) with totalizing capability would require upstream-of-gate-sensing, downstream-of-gate sensing, and gate-position sensing. The current practical method to record and process the information requires the equivalent of a computer at each site or power to support a transmission to headquarters. Local readout to aid the farm operator with irrigation management is another expense.

3. **High-Head Requirements:** Weir box systems seem doomed because of the high head differentials required between the delivery canal and the field water surfaces, and the difficulty of vertical placement without expert supervision by an engineer. This considerably increases installation costs, likely overriding any economies of low box material costs (precast concrete, or stainless steel boxes) with installation-expert requirements. Again, the reading must be processed for readout either by equipping each site with a computer or installing transmission equipment at each site.

4 **Vulnerability:** Added problems include the difficulty of maintaining head reading equipment because of possible damage from wildlife or vandals.

THE ALTERNATIVE OFFERED – RSA/Replogle Metering Pipe System

1. **No High-Tech Knowledge Required:** The pipe and propeller flow measuring system can usually be attached to the existing canal head gate and pipeline system that extends through the delivery canal bank. This attachment and field installation required ordinary construction skills. The pipe does not require extreme levelness or precision placement, as required by a weir box.

2. **General Measuring System Elements:** Irrigation flow measuring systems consist of a primary element that interacts with the water and a secondary element that provides information about this interaction. This information is usually the readout of the flow rate or the accumulated volume. Yet another element may be used to convert rate to volume or volume to rate. Both values are useful for irrigation management. The pipe and propeller meter system provides both values immediately without further processing, either at the site or back at the office. Only approximate field information is required to select a suitable pipe and reverse propeller meter system that can usually be installed in less than a half day by construction workers.

3. **Flow Accuracy:** Flow accuracy is sustained by the durability of the installed pipe and the use of commercially produced and calibrated propeller meters. Field testing has verified that the commercial claims of +/- 2% is approximately sustained and far exceeds most irrigation management demands.

4. **Tamper Resistant:** While not tamper proof, the system is tamper resistant. The units can be expected to operate for several cropping seasons with little or no maintenance attention.

5. **Convenient Data Collection and Reporting:** Required data for monthly reports can be obtained with a monthly reading by a meter reader. Little or no office-staff processing is required except perhaps subtracting the previous reading. No hours, or even dates, of delivery are necessary to obtain the reportable data.