PROPOSAL

Agriculture Water Savings System:

A Systems Technology Solution to Saving Water

Prepared for: California Water Agencies

Prepared by: Peter Hopper, Engineering Consultant (Retired): peteh007@yahoo.com

DRAFT : Prepared On: April 4, 2015

[version 3. Typos Corrected.]

EXECUTIVE SUMMARY

Objective

It has been made common knowledge that a significant fraction of California's water use is consumed by agriculture (Ag) customers. It is further, common knowledge that we need improvements to our water use models in California to be able to sustain our way of life. This proposal outlines a technical solution to work within the existing appropriative system to deliver adequate water to meet demand while saving both customers and water agencies money in the mid- to long-term. The proposed system is applicable to water supplied and used by NID's approximately 400 miles of canals and customer delivery ports.

This document hopefully may also stimulate additional ideas along these lines that can be realized for the betterment of our state's economy and way of life.

The document concludes that a capital investment of $1000 per customer would realize a water savings of 3 Acre.Ft per customer year. (Very conservatively, assuming a 1 MI/customer usage today.)

Goals

The proposed system could be implemented to achieve a >50% savings in mainstream Ag irrigation water use for the fraction of water delivered via appropriative systems. Customers would also see a reduced cost while meeting their volume demands. Additionally, water agencies would realize lower maintenance costs.

Solution

To effectively realize water savings, the proposed solution requires the following:

- Water agency (eg. NID) buy-in and deployment to implement the below items
- New (NID) water use pricing models which add to (not replace) the existing pricing frameworks
- Customer and water agency level Hardware and Software systems installed in a phased-in approach

Benefits of Proposal

- Significantly reduced overall water usage
- Reduced net flow out of reservoirs
- Reduced water waste
- Reduced pond water evaporation
- Lower water management headcount cost

PROPOSAL

- Reduced cost to the customer base
- Reduced water agency monitoring and maintenance costs
- Proposed system is entirely backward compatible with the existing system
- The proposed system is simple to install
- Proposed system is optional for customer base and would be incentivized purely by customer cost advantages relative to current costs. (Use less water, pay less)
- Reduced pond management and related costs for customer base
- Reduced mosquito abatement costs

Problem Statement

Water is supplied to Ag customers today via the NID water canal system which flows 24/7 during the six month delivery season. Customers determine their seasonal requirements and purchase a volume based upon the miner's inch unit, or equivalently, 11 gallons per minute (gpm). A large fraction of these customers base their water volume requirements on their peak demand observed in the warmest summer months of July-August. Most customers, however, do not require this level of water throughout the remaining 4 months of the water delivery season. Herein lies a potential savings opportunity.

To preface the details of the proposal, an analogy to the electrical supply system is beneficial. In the commercial electricity world, PG&E or SMUD charge customers per kW-h of energy used (*analogous to water volume*) and not unlimited use from a panel that provides a given magnitude (kW) of power (*analogous to water flow rate*). If customers were charged by the level of available power alone, the result would likely be a significant, un-fathomable waste of power usage. Thus, power companies sell their electrical energy by volume, or kW-h.

This same logic may apply to water if the volume of water can be accurately and reliably measured at the point of use. If one accepts that a volume based model (instead of a constant flow rate model) would improve the water demand situation, thus providing motivation to save water/water bills, the resultant problem is then defined as the ability to meter and control water volume.

PROJECT OUTLINE

The proposal details a system allowing a phased transition from flow rate (in miner's inches) to volume (in gallons) and allows customers a cost driven incentive to use less water when they don't need it. A customer would still be allowed to source larger amounts of water flow as needed. The miners inch orifice would be supplemented with an optionally installed, intelligent, automated, and electronically managed hardware "drop-in" replacement unit.

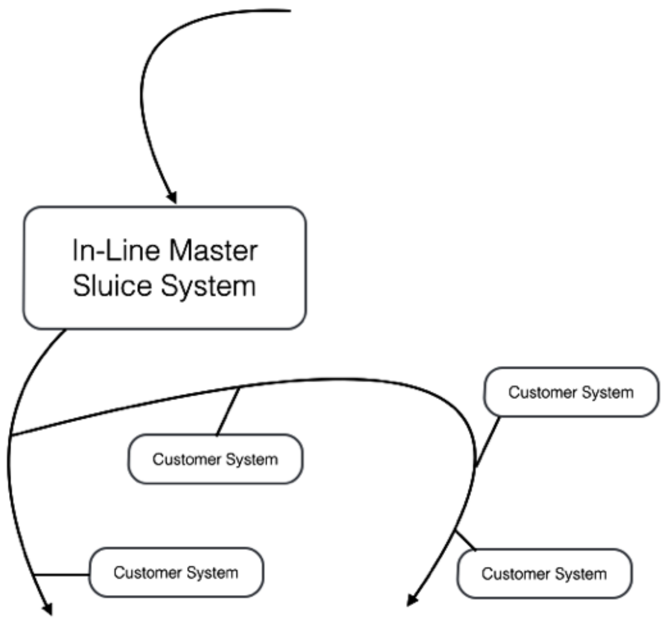
The optimal system would have the following components:

- Metering and control possible in both volume and time domains
- Simple and low cost installation
- Capable of remote operation
- Low maintenance cost
- Operates with existing system components
- Active control and future planning allowing fast and accurate system modeling and optimization

This is not a simple problem to solve, especially given the variations in the 'field' such as the case of dirty water potentially full of debris and algae, potential tampering, and other such environmental impacts.

System Proposal

The proposed system functional specification is outlined here and contains two types of hardware installations. Both are required to realize the gain in water savings and pertain to the customer via the point of use and to water agency personnel through delivery systems. Each customer would have a Point of Use "Customer system" installed at their current NID orifice box which would then be associated with their account. The system could be released as typical in the prototype/alpha/beta phases with milestones for passing each phase on a per customer basis. It could also be optional to the customer, however, most would be incentivized to request the system through cost savings, user control and transparency. The cost of POU system hardware is required to be low due to the potentially large adoption rate based on the total number of customers. A target cost of <$1,000 would allow 27,000 customers to be installed for $27M (about 40% of the current NID budget).



HARDWARE SYSTEMS - with up-stream sluice gate controlled to adapt to dynamic demand. The two types of hardware are essentially scaled versions of each other.

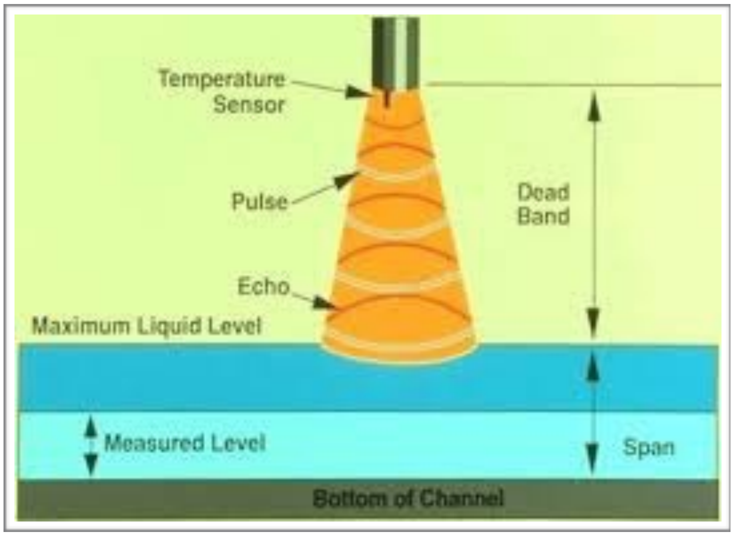
Hardware Functional Specification

1. Customer ‘Point of Use’ (POU) hardware system - one per customer and installed at the existing NID orifice point - each a computer controlled gate valve able to control the amount of water delivered to a customer.
2. Water agency ‘In Line Delivery’ (ILD) hardware system - A larger sluice gate installed in line with the canal - each a computer controlled gate able to react immediately to customer demands. Clearly modification of an existing canal junction or gate may be the most opportune during a prototyping phase - modifications may only involve software connectivity and thus represent minimal hardware cost.
3. Web site allowing customer monitoring, control, and personal optimization through personal account access via a “My NID” tool.
4. Master control system located at NID headquarters allowing monitor, control, and gate optimization.

Hardware Technical Specification

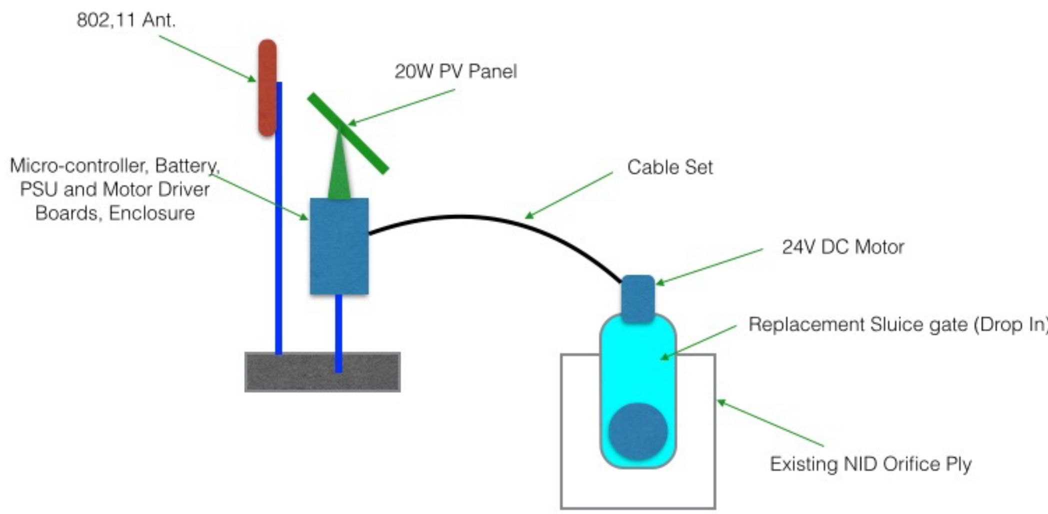
- Solar powered by 20 Watt Solar panels, charger, PSU and 6v (Motorcycle) batteries
- Low battery monitor LED (Red/green)
- Include DC-DC power boost switching regulator circuits and capacitor to provide 5V and 24V supply rails (from the 6V battery)
- Include a galvanized steel motorized sluice gate (example image shown in Figure below) capable of sliding exactly into existing NID plywood orifice slots
- Cable set between the sluice gate and the control box mounted on an adjacent steel post with a 16” square concrete pad
- Integrated opening size control in sluice gate so as to be able to open by set variable amount
- Electrical driver able to open the gate by a pre-calibrated amount equivalent to a factor of miners inches
- Manual hand cranked control capability on sluice gate to enable override in the event of power failure
- Manual up/down control of the sluice gate for local control
- Sluice gate open or close fully within one minute - relatively slower reaction time relates to lower power/cost
- Internet connection enabled via both wireless and hardwired ethernet connections included
- Internet connection includes integral router connected to WiFi antenna supporting 802.11n and 802.11a protocols
- Directional post-mounted POE based MIMO antennas employed to provide long range, low cost internet connectivity
- Driver board developed to accept control input signals from the internet and output instructions to the sluice gate motor
- A/D board to allow conversion of Analog Ultrasonic Water Height and Tamper Alert Signals to be relayed via IP to the central server
- Optional Ultrasonic water surface distance measuring arm and sensor mounted on top of the sluice gate
- Simple, low cost, 1” sch-40 steel antenna pole mounted into the concrete slab allowing antenna to point at a remote ISP antenna or relay antenna at a distance of <10 km with Line of Sight.
- ISP to be contracted to supply numerous data connection points at each antenna with low level amounts of burst data
- Hardware internet interface (RJ45) supplied for diagnostics and optionally for wired deployments - proximity may allow multiple systems to share a MIMO antenna with hard-wired ethernet connections between them
- 16” wide concrete pad installed to mount pole and system post for the system enclosure box and antenna
- Waterproof cable set between the gate motor and the control panel
- Additional mounting and stabilization hardware.

ELECTRIC VALVE - Example of small, computer controlled, 3" electric Knife valve installed at each customer box (POU) and secured to standard NID plywood orifice as a drop in replacement. Cost @20x : $200 ~ $300 ea. (Less in volume.)



ULTRASONIC WATER HEIGHT SENSOR - Standard Ultrasonic sensor optionally utilized to provide feedback to the server system management's control loop.

End Customer System Diagram - System would be installed into existing customers NID Box, as a "Drop-In" replacement. The control Box system would be installed a few feet away.



Software

Technical Specification

The software includes 4 components:

1. Central Server software
2. Customer System Microcontroller and Comms Software
3. App based Client Software with both management and customer modes
4. HTTP based web page software

- Application software developed to run on California's Apple iOS operating systems. Written in SWIFT language to maximize modern scalability. MultiPeer connection capabilities allow remote management of the client system BOTH with or without an available WiFi connection.
- Client System Software utilizing Arduino or raspberry-pie Micro-controller software - developed to run on the micro-controller and driver boards.
- Micro controller signals control the sluice gate operation in three methods - up, down, and to a predetermined opening in miner's inches equivalent units.
- Micro controller boards drive solid state relays which in turn supply 24V DC power to the sluice gate.
- Internet based controller server drives the Micro controller software.
- Customer "App" software communicates via IP to the OSX (NID) Server with requests relayed to the micro controller.
- Ultrasonic level measurement driven from the micro controller board and provides feedback to the server via IP. (Thus providing both real time feed back and 'tamper' sensing). If spike observed, system has been tampered with rather than gradual change caused by blockage.
- Simple, low cost database based on Core Data model sitting on SQL Light employed to hold relatively small number of records - a simple software system is envisaged to act as a server.

Customer Application Software Control Features

The primary incentive for customers to lower actual water use is not only to allow them to take only what they use, but also to increase transparency and to lower cost through relevant data presented in software applications. The following features would be built in to customer software package.

- Water pricing per gallon, per season, tabulation
- Adjustable rates visible for higher water usage rates
- Bill to date displayed on the screen
- Forecast bill with current use model
- User control of water supply rate on hourly, daily or monthly basis
- forecasted demands (for NID planning purposes)

- Rain gauge API with an adaptive response model option, as defined by the customer's control screen (eg. "If it rains, scale down by water use by 80% for 8 days per inch of rain.")
- Automated flushing routines (potential cost savings to NID maintenance)
- Clear, relevant output with tables and graphs displaying dollar savings to the customer:

  "You are on track to use a projected 34% of the equivalent of 2 Miners inches, this year"
  " You will save $433 dollars by adopting this model; this year."
  "Adding 1MI for 20 minutes on Tuesdays, will add $55 dollars to your annual bill"

NID Central Server Software Features

- Aggregated system reporting with customized views and breakdowns
- Water use monitoring and forecasting
- Water inventory reporting and forecasting
- Overall system control and monitoring
- Revenue modeling
- Pricing delivery control
- Customer communication
- http web page serving and customer application software serving
- Customer supply balancing and optimization
- Water Use optimization routines
- Just in time delivery parameter controls
- Flush control
- Connection test and system test
- Master system override

Program Adoption

A program would be developed as a series of phases:

- University program to prototype a scaled feasibility assessment "model" and to develop develop hardware and software control systems. Report out Quarterly. YEAR 1.
- Design of Full Scale Single Unit prototype end-customer system with associated software. YEAR 1.
- Design and test of larger, up-stream system to be installed in line with NID canal flow. YEAR 1.
- Move forwards upon successful completion of tests.
- Customer survey to identify willing beta customer base.
- Manufacture of 20x Beta customer systems using standard components. YEAR 1.5

- Prototype roll out of above 20x customer systems and one in line canal system, on a stretch NID canal, representing ~30% of new system customers. 30% is selected to generate meaningful test data. YEAR 2.
- Test and monitoring of 20X systems. Move forwards after successful conclusion.
- Customer system Manufacturing Cost reduction exercise. YEAR 3.
- Manufacture 1000 systems for deployment. YEAR 3.5
- Extend Roll out in line with nature's resultant annual increase in the urgency of demand. YEAR 3.5 …

Given customer's obvious sensitivity to the issue of their water supplies, a pilot program should be optional and use end customer bill reductions, as incentive. A system must require to be overridden during the role out phase. Clearly there is only a negative incentive to adopt a new system that may reduce the amount of water supplied to a customer. Never the less, the proposal requites that a number of customers serve as beta testers, during a pilot program.

Any stretch of NID canal might be used by a pilot program. A survey is proposed, educating, informing and requesting that participants try the new system with an associated cost. A stretch of NID water serving 30 customers with only 20 of them adopting the beta test program would be sufficient to test measure, test the performance of the architecture. These twenty customers might be given water at half price for the beta period. An incentive cost to NID of around $20k. Figure 3 depicts such a beta roll out.
Survey customer willingness to participate in beta program with cost incentive. Implement Pilot roll out at selected site.

The prototype components would consist of the following:

- An inline master Sluice. Single Unit. Custom.
- 20X Customer controlled systems.
- Server Software
- Customer iOS App Development
- Communications

A pilot system design would utilize Standard Electronic components in the prototype build as well as additional software components.

Subsequent scaling up to volume use would involve several additional costs including various non-technical components. The proposal here attempts to focus only on the technical solution costs.

BUDGET

Prototype System	Quantity	Unit Price	Cost
Hardware	20	$ 1,300	$ 26,000
Software (6 months ISP)	6	$ 50	$ 300
Development Labor (24months reduced version)	1	$ 400,000	$ 400,000
Total			**$ 426,300**
Finalized System	**Quantity**	**Unit Price**	**Cost**
Hardware for 20,000 customers	20000	$ 1,000	$ 20,000,000
Software	12	$ 50	$ 600
Development Labor (further 2 yrs full version w/ customer app)	1	$ 400,000	$ 400,000
Total			**$ 21,253,200**

CUSTOMER SYSTEM HARDWARE ITEM DESCRIPTION	UNIT COST
4” Sluice gate, knife valves installed into a plywood former to allow drop-in to existing NID Box	$250
20-Watt Solar Power Systems and Battery: Std electronics distribution channels	$150
Control Board based upon Ardiuno or Raspberry-Pie prototyping board	$100
Power management and motor driver boards. Standard parts: Texas instruments	$100
Nema3 Controller housing	$40
24V POE supply	$10
Antenna hardware - Ubiquitous Networks inc.	$100
Cable set from gate to control box and cat5/RJ45 set	$25
16” x 16” Concrete slap to install post for Box and Antenna	$25
Labour: 3 hours concrete and set post: NID Labor. travel time and install. 4 hours day at $50/hr	$400
Various other components	$100
TOTAL COST PER Proto INSTALLATION	**$1300**

DEVELOPMENT & SOFTWARE ITEM DESCRIPTION	UNIT COST
ISP integration - provide line of sight MIMO ~10mile + range, 802.11a, antennas to relay data as needed and manage ownership of communications under contract	tbd
ISP: Contractual Cost estimate at $100 per system “cluster” per month	$1.2k/yr
2x phD students to design system including software	$100k/yr
NID Overview engineering management	$100k/yr
Software systems development. Engineering mgmt.	$130k/year
Server System Cost. (Existing NID server or additional $5K)	$5,000
TOTAL DEVELOPMENT COST	

Hard Dollar & Water Savings

Water Savings

The savings calculations presented here should be scrutinized; employing real data instead. Some assumptions as to number of NID customers and their average water use today have ben made. Never-the-less, even if some assumptions are inaccurate, the qualitative conclusions are still clear. Signifiant water savings are to be had.

As an example, to gain insight into the order of magnitude of the potential savings:-
Assume the 20 prototype systems are deployed with a current use of 3 miners inches.
Each new system would improve water control to deliver 50% of the current system's amount. This, by Scaling the amount of water used in the cooler months, and not allowing water to flow though a fix orifice, 24/7.

A single customer using 1 Miner's Inch of water and todays system uses: gallons of water per year.

1 customer x 1 MI x 11gpm x 60mins per hour x 24hrs x 7days/week x
x 25 weeks/year = 2.7 Million Gallons per season. (7.5 Acre ft.) (An acre.ft is 0.36million gallons.)

The lack of saving's incentive, seasonal adjustment, metering and control means that 50% of this is wasted.

1 Customer's water savings, currently being supplied with 1 MI is thus > 3 Acre.ft
This number may be scaled by per customer use, multiplied by total number of customers.
20,000 customers @ 1mi, would save: ~20,000 x 3 acre.ft = 60,000 acre.ft.

This is a vastly conservative number, as the typical demand from a customer is greater than 1 Miners inch. Thus savings are likely be far higher when "real" numbers are plugged in to these calculations.
These numbers do serve to give a sense of the magnitude of the amount of water that might be saved by computerizing the deliver of such water however, for a single water district.

NID charges around 30 milli.cents per gallon to a customer today (assumption)
A customer, using 1 Miner's inch, savings per year would be approx $110.

ROI

Savings of $110 per $1000 for 1MI customer: ROI is 11% per year.
Savings of $220 per $1000 for 2 MI customer: ROI is 22% per year.
Savings of $330 per $1000 for 3 MI customer: ROI is 33% per year.
Savings of $440 per $1000 for 4 MI customer: ROI is 44% per year.
Savings of $550 per $1000 for 5 MI customer: ROI is 55% per year.
Savings of $660 per $1000 for 6 MI customer: ROI is 66% per year.
etc.

Given these ROI calculations: higher savings are obviously apparent for the cases customers with higher water use rates, although 1MI customers are also opportune.

ADVANCED CONTROL SYSTEMS

Exploiting Electrical Engineers Proven "*Tools of the Trade"*

Once a computerized delivery framework has been installed and deployed, significant water savings may be realized by optimization the water demand-delivery control system's algorithms. As with all complex optimization problems, algorithms demand the use of a good underlying physical model. In this case, of the water delivery network. This model provides the basis to being able to make informed quantitative decisions. Knowing exactly when and by how much to supply more water to meet a modeled demand. (Beyond being theoretical, such techniques are used commonplace, for decades, in the design optimization of any Semiconductor device i mass manufacture today, each containing Billions of sub-nets and components.)

Adaptive Demand Software Algorithms

The direct analogy of the the electrical world with potential water management techniques is apparent on several levels. Certain power demand algorithms developed several years ago have been employed in the Microelectronics Power Management fields that enable critical power reductions. Importantly, these specific algorithms enabled the realization of such revolutionary low power electronics systems as todays modern smartphones and tablets. (Of note: the Adaptive Voltage Scaling (AVS) algorithms provided for a Look-ahead approach to supplying power to a microprocessor resulting in significantly less power consumed by the component Microprocessor or Graphics Processor.)

A water management and distribution optimization system may also be modeled using simple electrical engineering Computer Aided Design tools (e.g. "Spice"). A simulation environment, applicable to electrical circuitry, may just as well be used by an engineer solving a water management optimization problem. It is envisaged that water management software algorithms may be advanced, using such software as a test platform. Utilizing these look-ahead algorithms, “***the system can predict the use of transient water demand, based upon it’s knowledge of its distributed canal system and network of customer ‘loads’***.”

Beyond the development and delivery of such basic algorithms; there is potential for the additional cost effective funding in the form of a phD program to run several projects to develop such advanced (AVS) algorithms. UC Davis would be a likely candidate given location and familiarity with agriculture and conservationism. This organization, with its associated skill set, would be an ideal University platform to provide and subsequently refine, such software layers. The server software platform should be selected in tight association with NID’s adopted server choice. The same platform should be adopted for obvious reasons.

Software development should be implemented in the following layers:

Basic control and monitoring systems layer development, test, debug.
“Simulation of an NID water supply network by using an Equivalent Active RCL net-list.”
Using a simple analog-digital mixed signal electrical circuit simulator; NID components (Canal Sub-section Length, Width and Slope, reservoirs, gates, Sluices, Pumps, Customer orifice’s) would be represented by their electrical analogs (Voltage Sources, Current Sinks, Distributed RC networks). Conventional Customers with fixed orifices would be represented with fixed value current sinks. The new system would add a series of active current sinks (Analog transistors) to replace the static current sinks. The canals would be represented by disturbed RC passive networks - a physical map if the canal would be used to extract the “equivalent net-list”. These terms are all very familiar to any electrical engineer dealing with high speed circuitry. Again the overall intent of such algorithms, is to preserve system (iPhone) “battery life” (California’s reservoir water).

Once such a platform is in place: any number of Transient Demand algorithms similarly can be built on top, as a series of software layers, each encapsulating the underlying capabilities. Whereas the electrical engineer would be dealing with picosecond order transistors switching, each demand a pulse of electrical energy; a water delivery switch would work in time scales of minutes and hours or even days. The math problem is the same but easier due to simpler over all network. Cost and price optimization follows.

Given that a new system would support transient use and the ability to serve transient responses, a whole host of optimization Algorithms should be developed and added to better balance the distributed load. Consider for example, the case when customer A uses water at a time that customer B is not. And again the case when both customers demand water at the same time. An adaptive management system can support this demand complexity, best, if all water supplies and demands are controlled. ***Water demand is inherently predictable, based upon the stated, modeled, optimized and captured requirement of each customer***. Demand balancing incentives may be provided to each customer in the form of a cost benefit in milliCents per gallon. The algorithms would all run on the central NID server. Smaller customers, looking to save small dollars, would be presented with a series of ‘Open slots’, each representing opportunities to use water at a slightly lesser $/gallon rate. Beyond, this, for the case of flood irrigation, where customers consider the amount of water, and the time of use to minimize evaporation; may be allowed to optionally turn the control of the exact time of water flow, over to the master NID algorithms. As an example: customer A may be incentives to adopt a lower cost ‘community collaborative’ scheme where he receives 2000 gallons of water at a time when the systems decides, but constrained by himself, to ‘any time’ between 6pm and midnight, on Mondays and Tuesdays.

As a further simplified example: customer A and customer B each turn on their sluice gates at 7am. Customer B is 3 miles down stream from customer A. Each section of the canal has been modeled as an equivalent RC delay line (depending upon it’s capacity, its loss, its width, length, depth, surface roughness, and slope). The time for a pulse of water to move through such a section is thus predicted and may be calibrated too (parameter extraction) to ‘fit’ the model. ***The central server knows that Farmer Smith will demand water at 6am because his local model demands it. The up stream sluice gates a, c and d can be opened 7, 15, 23 hours ahead to accommodate both transient demands, accommodating the delay line effect of a pulse of water, flowing down the canal, through each modeled segment until it arrives as Farmer Smith.*** More importantly, from a conservation point of view, up steam sluices at reservoir sources can close in line with the pre-calculated demand transient on the ‘down’ cycle.

Optimally, the water level at the end of each network branch, adjacent to the “last customer in the line” , would be maintained at a very low level; modulated enough only to satisfy exactly the demand of the last customer. This would be a low waste situation. ***The water level “buffers” of today could be avoided.***

Weather status may be simply incorporated into algorithms. Whereas today, a customer may simply open up their demand when the weather feels hot; and the water management of today responds by trying to keep up and to maintain a threshold level. In this case, the future automation system can simply ‘look ahead’ and be automatically ready with the supply. And open up the customers supply line according to a preset model parameter set.

Example:
IF temp.time rises above 80F.hrs = > 5 x 10 hours, THEN multiply deliver amount by 20% for ‘time’ hours. etc etc.
Thus an efficient amount of water is fed to crops without human intervention- and with little waste.
Up stream delivery gates can for-see this request coming days ahead based upon modeled and predicted weather profiles. Thus ***sluice gates, operating under the model, miles up stream have responded even before the weather temperature has risen; and, cut off again***.

Water may be considered as a series of transient pulses, rather than static water levels.

Larger Customers could also link weather gauges to their local stations to provide local decision making criteria such as precipitation and temp also. Providing last minute adjustments to the local gates delivery amounts.

In summary, this important advantage of having full exposure to the details of exact future end customer demands is that water may be supplied via the Just-In-Time algorithms described above; thus avoiding over supply and supply guesswork.

As a case example: Today, a heat wave

SUMMARY

- California needs to use water more efficiently and frugally.
- Customers waste water as a result of the charging model adopted today.
- A new system, that charges customers by the amount of water they use, rather than the amount of water available to them would realize >50% savings.
- A modern, practical, technical solution is proposed based upon design techniques in use today in the Semiconductor Industry, among others.
- The calculated hard dollar savings, water savings and ROI time-frames are both attractive and necessary.
- Various assumptions have been made though-out. Further refinement is suggested to revise these calculations, based upon the latest known empirical NID data.
- A capital investment of $1000 per customer would realize a water savings of 3 Acre.Ft per year. Very conservatively, Assuming a 1 MI/customer usage today.
- A broad range of water savings algorithms may be developed and exploited towards a far improved water usage model than is the case today. However, all of these fore-seen automated algorithms rely fundamentally upon being able to control and measure individual end customer use; and thus by adopting this form of automated system.
- Water Savings of $440 per $1000 for a 4 MI customer: ROI is 44% per year. Break-even is thus <3 years.
- Again, the intent of this document is to encourage the adoption of a pricing model based upon water volume use in addition to the current ‘Miner’s Inch’ water flow rate model.
- The optimum position is to : ***<u>drive to replace the pricing model’s “$/Miner’s inch” model with “$/Gallon”</u>***

About Author:

Peter Hopper is a retired Consultant Electronics Engineer

Previous positions include:

Distinguished Member of the Technical Staff with Texas Instruments Corp.

Director of Semiconductor Device Research with National Semiconductor Corp.