Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

AGRICULTURAL WATER ENERGY EFFICIENCY

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ITRC

moving water in new directions

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Agricultural Water Energy Efficiency is the final report for the Agricultural Water Energy Efficiency project (Contract Number 500-06-040) conducted by the Irrigation Training and Research Center at California Polytechnic State University, San Luis Obispo. The information from this project contributes to PIER's Industrial/Agricultural/Water End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1351.

ABSTRACT

Beginning in 2007, the Irrigation Training and Research Center at California Polytechnic State University, San Luis Obispo, contracted with the California Energy Commission's Public Interest Energy Research Program to undertake a large, multitiered study on agricultural water energy efficiency in California. The study was broken into the following research tasks: Task 1: Administrative; Task 2.1: Irrigation district energy survey; Task 2.2: Conversion to groundwater pumping with drip/micro-irrigation systems; Task 2.3: GIS-based water scheduling and software system; Task 3: Irrigation component energy analysis; Task 4: RD&D competitive solicitation; Task 5: Technology transfer. The resulting survey, research, and testing data from these tasks led to a better understanding of current agricultural operations in California and pointed out new avenues for energy conservation that could have widespread effects on energy efficiency in the state's agricultural industry.

Keywords: California Energy Commission, PIER, energy, irrigation, pump, agriculture, drip irrigation, micro-irrigation, groundwater, VFD, GIS

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EXECUTIVE SUMMARY

Task 2.1: Irrigation District Energy Survey

The Irrigation and Training Research Center (ITRC) of California Polytechnic State University, San Luis Obispo completed this survey on behalf of the California Energy Commission's Public Interest Energy Research (PIER) Program. The survey established a benchmark for the present status of the pumping systems used by agricultural water districts in California and determined the districts' needs. The needs discussed involve technical assistance, research, grant and low-interest loan funding, and district-related policy issues. For the survey, researchers chose 30 agricultural water districts selected based on energy use per acre of irrigated area, size, geographic location, and distribution infrastructure.

To complete the surveys, ITRC visited each participating district and asked the survey questions verbally. Most of the questions were discussion-based to encourage open answers (rather than multiple choice). The hope of the open discussion was to ignite innovative ideas and allow free, out-of-the-box thinking to develop. Even with open discussions, the districts' answers revealed trends in ideas and concerns.

Overall, the districts surveyed expect a significant increase in load and electricity needs in the next 5-10 years. Nearly 75 percent of the districts surveyed expect an increase in load and electricity use.

A number of the districts surveyed, especially those on the west side of the San Joaquin and Sacramento Valleys, expect increased crop demands from an increase in permanent crop acreage and in some cases an increase in overall acreage. Past studies conducted by the ITRC indicated that districts on the east side and middle of the two valleys are seeing a decrease in cropped acreage due to urbanization. It may be that farming is moving away from the lower areas that are typically gravity-fed water, to higher areas that require increased pumping and typically have poor soils for growing crops. This is a significant event for future electricity demand.

Task 2.2: Conversion to Groundwater Pumping With Drip/Micro-Irrigation Systems

A large-scale survey of connective use irrigation districts in the San Joaquin and Sacramento Valleys sought to identify trends in groundwater usage among those districts that have converted to drip/micro-irrigation systems. The term "conversion acres" is used to identify land on which farmers used only groundwater for drip/micro-irrigation, even though surface irrigation water was available. Significant findings of the survey were:

- Twenty-one districts (which together include about 2 million acres of irrigated area) reported conversion acres. Roughly 3.6 percent of that acreage (73,000 acres) has been "converted" to groundwater when farmers switched to drip/micro-irrigation. Fourteen of these districts anticipate more conversion in the future. ITRC thinks that the conversion will be more rapid and greater than district personnel suspect.
- The dominant factor that influences conversion was the lack of flexible water delivery service to fields. Districts with rotation schedules had conversion rates 3.5 times higher than districts with 24-hour arranged deliveries. Districts with more flexibility (for

example, deliveries that require fewer than 24 hours to arrange) did not report any conversion acres.

- The conversion trend has been reversed by one district (Chowchilla Water District) through a program that combined district modernization and new pricing policies. The extra energy required for groundwater pumping on the 73,000 conversion acres is estimated to be 76 Million kilowatt-hours per year.

Task 2.3: GIS-Based Irrigation District Flow Routing/Scheduling

In 2007, ITRC began developing a prototype of an intelligent and scalable real-time GIS-based water scheduling and routing software system for irrigation districts. This system is capable of integrating multiple data sources into an information access and management service featuring collaborative tools with automatic reasoning and analytical capabilities. Improving the infrastructure and management capabilities of irrigation districts to provide flexible delivery schedules and increase participation in peak demand reduction programs was identified as having significant potential to achieve energy conservation and resource efficiencies.

Development of the decision support systems (DSSs) covered in this final report was led by ITRC with cooperation from the Imperial Irrigation District where the DSSs were piloted in real-world conditions. A number of experts and consultants, primarily from Keller-Bliesner Engineering (Logan, UT) and Davids Engineering (Davis, CA), were extensively involved with the project, including complex programming across multiple software platforms. This project benefitted significantly from the fact that it was part of the design and planning for a major ($200 million) water conservation program in the Imperial Irrigation District.

The results of this study highlight a number of important lessons that will be applied towards future modernization efforts in the state's irrigation districts. These key lessons are outlined in this report, showing a significant progression in the conceptualization, organization, and execution of irrigation district-level DSS tools. As expected, the project was partly a mission of discovery. Even though some of the individual components related to irrigation district DSSs are already used in multiple places for multiple purposes, this was the first serious effort to integrate them into a workable package. This study also showed that some of the original ideas were either too difficult in practice to be realistic, or that they could be better accomplished by other means, which were only identified as a result of attempting such an effort.

Task 3: Irrigation Component Energy Analysis

In Task 3, ITRC originally planned to develop an energy wise label program for agricultural irrigation equipment. However, Task 3 was modified to both develop the label program and also include a new major subtask to characterize irrigation pump performance in California. Task 3 consisted of the following stages:

Stage 1	Index irrigation system components and potentials for energy conservation
Stage 2	Determine current work in progress
Stage 3a	Discuss with utilities and state agencies
Stage 3b	Develop standards with manufacturers

Stage 3c	Develop a testing laboratory at California Polytechnic State University, San Luis Obispo
Stage 4	Testing related to ENERGY STAR® label

Task 4: Prepare and Administer RD&D Competitive Solicitation

Task 4 was eliminated for multiple reasons. Manufacturers felt that unless a development project was a high marketing priority, they could not afford to spend time on it. Ideas such as reducing pressure loss in pressure compensating emitters, lower losses through pressure regulators, and others were not considered high priority for companies.

Task 5: Technology Transfer

Technology transfer activities appear at the end of this report. Once the final report is approved by PIER, several professional papers will be developed and presented at professional conferences.

Note: All tables, figures, and photos in this report were produced by the authors, unless otherwise noted.

TASK 2.1. IRRIGATION DISTRICT ENERGY SURVEY

Chapter 1: Introduction

The Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo has prepared this report under contract with the California Energy Commission's (Energy Commission) Public Interest Energy Research (PIER) Program. ITRC has provided technical assistance to agricultural water agencies throughout the western United States on a broad range of issues including water and energy conservation, improved water delivery service, and acting as administrator for the highly successful Energy Commission Agricultural Peak Load Reduction Program (APLRP).

The goal of this survey was to determine the present status, and current and future needs, of irrigation districts in regard to energy use for agricultural irrigation water pumping. For districts that pump water (surface or ground), electricity is typically the districts' largest expense. Over the years districts have found innovative ways to reduce power costs, which in turn reduce the cost of water to their farmers. This report will summarize some of these innovations as well as present ideas that districts would like to research or implement but may need financial assistance in order to make it feasible.

Figure 1: Berrenda Mesa Water District's 9,900 HP (10 pumps total) pump station.

With the Energy Commission APLRP the district was able to curtail 4.67 MW of peak energy use, but in the past 2 years the increased demand from additional cropped acreage has led to more on-peak pumping.

Source: Irrigation Training and Research Center

District Selection

ITRC surveyed thirty agricultural water agencies (water districts) throughout California that had significant pumping. Districts were selected based on previous energy use estimates used in the *California Agricultural Water Electrical Energy Requirements* (Burt et al, 2003) prepared for the Energy Commission. Selection criteria included:

1. High kilowatt-hour (kWh) electricity use per acre of irrigated area
2. District size – district sizes were selected so that ideas from both small and large districts could be incorporated
3. Varying reasons for pump use – surface water, groundwater, drainwater, etc.
4. Location – selected districts were spread out from the Oregon-California border to the base of the Grapevine in Kern County

Table 1 lists the districts that participated in the survey and their approximate irrigated acreage. The 30 agricultural water districts surveyed serve approximately 1,900,000 irrigated acres of the total of approximately 9,000,000 irrigated acres in California.

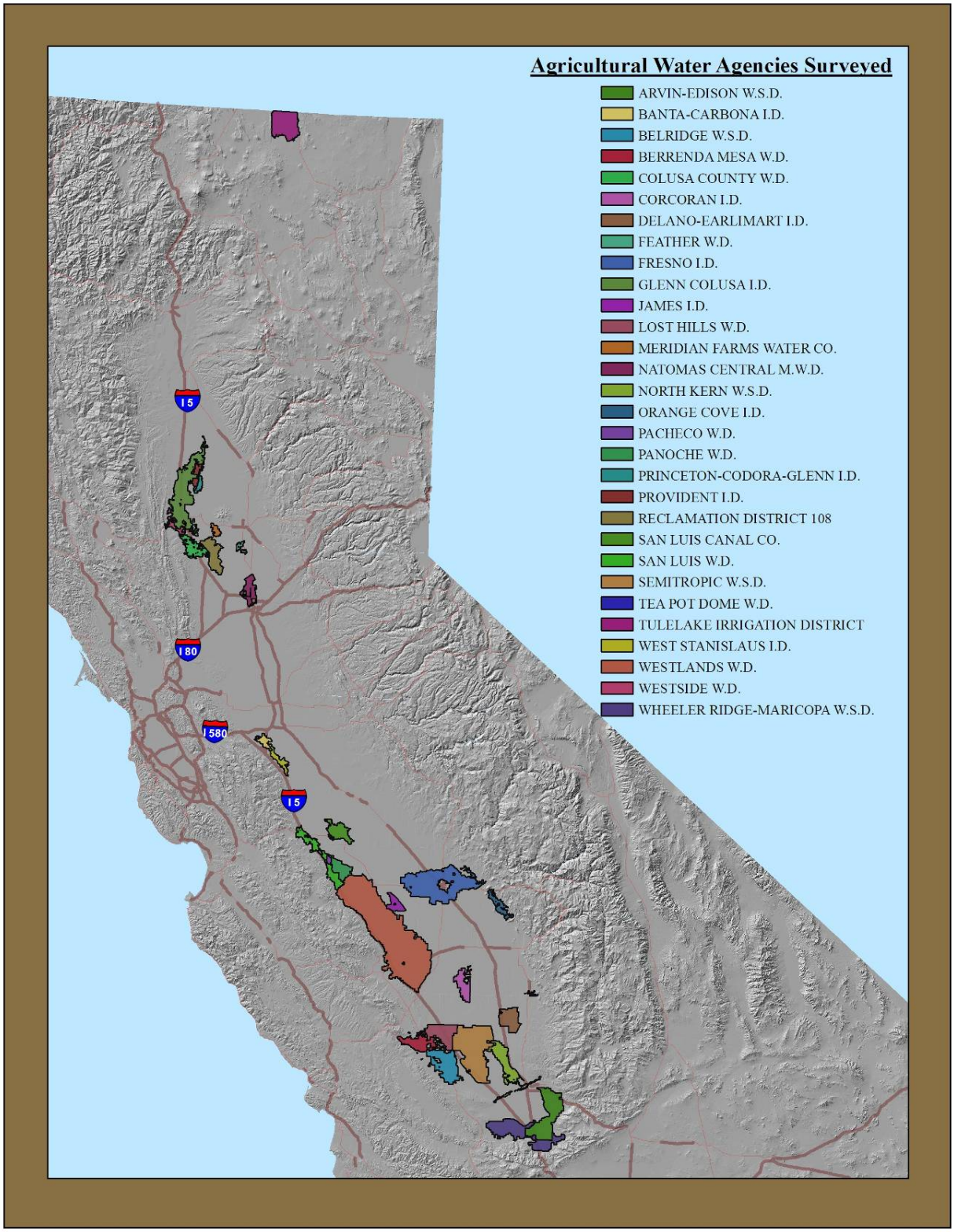
Table 1: List of participating districts and approximate irrigated acreage

Agricultural Water District	Approximate Irrigated Acres
Westlands Water District	530,000
Fresno ID	163,000
Semitropic WSD	143,000
Glenn-Colusa Irrigation Dist	134,000
Arvin-Edison Water Storage District	107,000
Wheeler-Maricopa WSD	90,000
Tulelake Irrigation District	64,000
North Kern WSD	60,000
Lost Hills WD	56,000
Delano-Earlimart ID	55,000
Reclamation District 108	50,000
San Luis Canal Company	47,000
Berrenda Mesa WD	46,000
San Luis Water District	45,000
Colusa Co. WD	41,000
Belridge Water District	39,000
Panoche Water District	37,000
Orange Cove Irrigation District	27,000
Natomas Central Mutual Water Co	26,000
Corcoran ID	22,000
James Irrigation District	22,000
West Stanislaus ID	22,000
Banta-Carbona ID	16,000
Princeton-Codora-Glenn ID	12,000
Provident Irrigation District	12,000
Meridian Farms W C	8,000
Westside Water District	8,000
Feather Water District	7,000
Pacheco Water District	4,000
Tea Pot Dome Water District	3,000
Total	**1,896,000**

Source: Irrigation Training and Research Center

Figure 2 shows the locations of the participating districts.

Figure 2: Districts participating in energy survey



Source: Irrigation Training and Research Center

Chapter 2: Survey Results

Unlike many surveys, the questions in this energy survey were not multiple choice or yes/no (see Appendix 1). Most of the questions were meant to begin a discussion and keep it focused. This allowed district managers and key personnel to share their thoughts openly and not feel limited to a few, pre-determined choices. A portion of the survey asked specific infrastructure and energy use related questions (e.g., How many surface water lift pumps does the district have?), which can be statistically summarized.

Most of the answers were district-specific and required more of a discussion than a statistical analysis. The Energy Survey results are presented in the sections outlined below:

- District-recommended research focus
- Districts' suggestions for grants, rebates, and low-interest loans
- Policy issues that could reduce energy demands
- Current pumping infrastructure and maintenance
- Plans for the near future
- Successful past projects

District-Recommended Research Focus

Even though this was an open discussion there were a few research needs that multiple districts addressed or that were innovative enough to warrant mention. The following items are in no specific order:

Time-of-use water meters: Currently, water meters typically totalize the volume of water delivered to a water user, which is manually recorded on a weekly or monthly basis. A water meter that could record and store water use by time of day would allow districts to price water differently for on-peak versus off-peak hours.

Low-head hydro generation technology: Generation in general was a common theme among water district managers that participated in the survey. A number of managers would be interested in installing low-head hydro generators for locations with a significant drop, if the technology was cost-effective. Past experience by a number of districts with different low-head hydro generators suggests that the technology needs more research.

Energy Studies: While districts have some ideas about energy conservation and peak load reduction, the average district may not have time or funding to investigate them. A program is needed where technical assistance can be provided on a district-by-district basis to determine the most effective methods of energy conservation and peak load reduction. Possible topics include:

- Checks to see if pump/motor combinations are correct.
- Technical assistance to determine what projects would be most cost-effective in shifting away from peak load pumping.

Solar generation: Solar energy was one of the most common issues discussed among districts. It will be discussed in following sections as well. From a research perspective, making the technology more cost-effective is the key issue, whether that means more generation per unit of solar panel area or simply building the panels for lower cost.

More efficient pump impeller/bowl design: With new technology, including more comprehensive computer models, some districts wonder if there could be a more efficient bowl or impeller design.

Flow measurement in constrained areas: District pump stations were not always designed with sufficient straight unobstructed discharge pipe to obtain an accurate flow measurement during a pump test. This prevents some districts from being able to accurately check their pump efficiencies. With further research it could be possible to design a flow measurement strategy that could more accurately measure flows.

Water conservation: On-farm and district water conservation is directly linked to irrigation district pumping. Energy-saving ideas include cost-effective canal seepage reduction, improved irrigation systems, tailwater return systems, canal automation, SCADA, and regulating reservoirs that can limit pumped water losses. Improved education of irrigation methods, technology, and proper operation on-farm would be a benefit.

The following table shows a number of research issues that districts felt would be beneficial to look at. Also shown are the number of districts that mentioned each item.

Table 2: Research issues brought up during the survey

Research Idea	Count
Technical assistance to individual irrigation district to determine peak load reduction projects, analysis of pump/motor combinations to determine if they are the most appropriate, overall energy analysis, feasibility studies, etc.	5
Low head hydro-generation	5
Time-of-use water meters	3
Higher efficiency pumps	3
Research technology that would allow the district to analyze the distribution of demands through the district's load monitoring system, and to enable the prediction of when peak loads will occur	2
Reduced canal seepage	2
Improved flow measurement in constrained areas	2
Improved water conservation techniques	2
Float assemblies to allow growers to go off-peak and decrease waste	1
The ability of districts with rice to switch to off-peak	1
VFDs in areas with a lack of storage at the ends of pipelines and a high degree of slopes	1
Ways to keep the Feather River water levels higher at low flows	1

Source: Irrigation Training and Research Center

Grants, Rebates, and Low-Interest Loans

This section of the survey had the highest number of responses. Irrigation districts typically do not have the capital to invest in large-scale electricity efficiency or peak load reduction programs. In many cases, especially in lower head pumping situations, the payback time is greater than 10 years, making many projects economically infeasible.

A number of interviewed districts had participated in the Energy Commission APLRP in some way. Many districts received rebates to have their pumps tested, repaired, or both. Others participated in the peak load reduction portion, which may have included adding reservoir storage, or installing a SCADA system so that pumps could be managed more easily.

Since the Energy Commission APLRP for Irrigation Districts ended in 2004, most districts surveyed have done minimal or no significant projects to reduce energy demands or shift load other than regular maintenance. Many districts have older pumps and motors that require significant maintenance and rebuilding. This takes up a majority of the districts' annual budgets for maintenance, leaving little funding for proactive solutions.

Nearly every interviewed district that participated in the Energy Commission APLRP for Irrigation Districts asked if another similar program was coming up. While many districts know about the California Public Utilities Commission/PG&E pump testing and repair rebate program, most do not utilize it.

The following responses were common among district managers:

Pump testing and pump repair rebates: A program is needed that is built for the needs of irrigation districts. Issues such as having to estimate individual pump power consumption when a single meter reads multiple pumps or districts using WAPA or project power need to be incorporated into the program.

District peak load reduction: Issues that require significant capital investment also require grants and low-interest loans. These projects include:

- Increasing storage at the ends of pipelines
- Increasing pumping capacity to pump the same volume in 18 hours instead of 24
- Installing larger diameter pipe in several areas
- Implementing supervisory control and data acquisition (SCADA) systems to effectively operate the irrigation system for peak load reduction

On-farm peak load reduction: Some districts are interested in acting as an administrator for grants and low-interest loans to their growers to encourage the installation of irrigation systems with larger capacities so that the farmers can operate off-peak, resulting in the district operating less during the peak period.

On-farm water conservation: Limiting water losses on-farm directly impacts district energy use. Items such as tailwater return systems and irrigation methods with high distribution uniformities may be beneficial. Both of these examples require additional pumping pressure, but may result in a net positive in some districts.

Solar rebates or grants: Over a third of the districts surveyed stated that they either have looked into or wanted to look into adding solar generation of some type into their operation. However, the cost of solar has limited their installation.

Table 3 shows common projects that the districts would like to see grants, rebates, and low-interest loans for.

Table 3: Projects for which districts would like grants, rebates and low-interest loans

Grant, Rebate, Low-Interest Loan Needs	Count
Pump efficiency test and repair rebates specifically for irrigation districts that is inclusive for WAPA, project power, and water users in utilities other than PG&E	21
Reservoir storage and increase pumping and pipeline capacities	14
Solar incentives	11
SCADA and telemetry for remote monitoring and control	5
Grants to farmers for improved irrigation systems, tailwater returns, larger system capacities so they can go off-peak	5
VFDs for improved operation and energy efficiency	3
Incentives for farmers to go off-peak. Grants for TOU meters, infrastructure, research and pilot programs	3
Expanded TOU program with additional deep wells for off-peak operation	2
Grants to encourage using larger pipelines to reduce friction	2
Recycled drain water utilized at a lower lift than supply water so that the drain water does not have to be lifted out of the district	2
Irrigation system evaluations	2
District infrastructure improvements to increase water delivery service so farmers do not switch to groundwater when installing drip and microspray systems	2
Premium high efficiency motors	2
Conjunctive use through water banking to increase GW levels	1

Source: Irrigation Training and Research Center

Policy Issues

In general, policy issues were not as high a priority as the first two categories of the survey. Policy issues that were discussed ranged from dealing with the local utility to dealing with the state government.

Solar program grants are only for less than 1 MW of generation per meter: Some districts have a single meter to measure multiple pumps, an entire pump station, or even the entire district. Semitropic WSD has a single meter that accounts for all of the pumping in the district. The district would like to install a number of solar arrays to offset this pumping. However, the district is not eligible for grants because the size of all of the arrays combined would be greater than 1 MW. (For more information on the California Solar Incentive (CSI) program see http://www.pge.com/about_us/environment/solar/CSI_Incentives.html.)

SMUD does not accept irrigation districts for agriculture tariff: Sacramento Municipal Utility District does not accept a local water company for an agriculture electricity rate tariff even though the water agency supplies only irrigation water to agriculture. The water agency is considered a commercial industry. All other major utilities allow agricultural water agencies to utilize agricultural electricity rate tariffs.

Place-of-use restrictions: In today's water industry flexibility is key to both water and energy conservation. This is especially true in regions that are in the middle of water transfers, groundwater banking, and conjunctive use projects. Steve Lewis of Arvin-Edison Water Storage District presented this issue to the Energy Commission on June 21, 2005

(California Energy Commission, 2005). To summarize the actual situation that Mr. Lewis presented:

> *In 2004, the district was banking water in its facilities (allowing water to percolate into the soil) from Friant-Kern Canal while at the same time pumping water 35 feet away to return it to Metropolitan Water District. The infrastructure exists to trade the water that would have percolated for the water that was being pumped; however, place of use restrictions dictate that CVP water cannot flow to Los Angeles. Since the pumping requirement at the banking facilities is about 1,000 kWh/acre-foot it would have saved a significant amount of energy to substitute the water.*

Perhaps a No Harm No Foul clause could be implemented in the place-of-use restriction to update the rules to reflect the needs of water agencies.

Carbon credits: Carbon credits are becoming a big topic in the discussion of global warming. For example, what is the cost of decreased water allocation on carbon (carbon dioxide specifically) uptake? Reduced water allocation can lead to reduced cropping (fallowing) or vegetative health leading to less carbon being consumed. Districts are asking if industries associated with agriculture – specifically, the farms themselves – should be given a positive carbon credit since the crops they grow take carbon out of the air.

Table 4: District policy concerns

Expanded water user education on good water management is needed
Solar program grants only allow <1 MW of generation per meter
Place-of-use issues – Federal regulators make it difficult to switch federal water for state water. For example, MWD called on previously banked water while Friant was banking excess water. Because of federal regulations, the districts were pumping water and banking it at the same time in the same location
Reduced demand charges have been helpful. Reducing the peak demand charge more could encourage less peak usage (once a district has to use the power during the peak they figure they might as well use it more since they are already paying the demand charge)
SMUD does not allow irrigation districts to use agricultural rates
ITRC should continue to be funded – It is the only resource that has experience with the full range of irrigation industry from farm to the district level, and expertise in energy and water conservation
A 3-year tariff for power costs is not long enough to complete an accurate cost/benefit analysis for projects
PG&E has recently discontinued credit for power factor improvements so the district has no incentive to improve power factor if they are not going to add more capacitors

Source: Irrigation Training and Research Center

Current District Pumping and Maintenance

This section of the survey was numerically based so that simple statistics can be used to summarize the results. The districts were asked the present status of their pumping facilities. Pumping facilities were broken into three categories (originally there were four categories; however, none of the districts surveyed classified any well pumps as drain well pumps):

1. **Deep groundwater well pumps:** This is any groundwater pumping for irrigation use by the district. It excludes pumping to maintain groundwater levels.

2. **Surface supply pumps:** This includes lift pumps and booster pumps within a district for irrigation water use. This category excludes pumping directly out of drains.

3. **Surface drain pumps:** These pump drain water out of drains. They could pump drain water into irrigation canals or pipelines but once it enters the irrigation system the pumping is then done by surface supply pumps.

Table 5 shows the basic pump information gathered. The total average electricity use is for an average water year. Table 5 indicates that the 30 irrigation districts have over 450,000 HP of nominal connected load in the system. The nominal horsepower is also called the nameplate horsepower.

Table 5: Basic pump data gathered from the 30 irrigation districts

	Deep Well Pumps	Surface Supply Pumps	Surface Drain Pumps	Total	Number of Districts that did not know
Total Number of Pumps	646	1,199	200	2,045	0
Pump Efficiencies Checked Per Year	226	185	2	413	0
Total Nominal Connected **Horsepower**	149,200	296,400	11,100	456,700	0
Total Average Electricity Use (**MWh/Year**)	216,700	426,200	13,900	656,800	1

Source: Irrigation Training and Research Center

In some cases districts surveyed did not know a value in the survey. For example, in Table 5 one district that pumped surface water did not know or even have an estimate of how many kilowatt-hours (kWh) of electricity it used over a typical year. In this case, the district received power from the USBR and the electricity bill was incorporated into the water bill. The district did not summarize the electricity usage separately. Other districts had varying reasons for being unable to answer certain questions.

Table 6 summarizes the districts' stated average pump efficiencies. From over 1,100 pump tests conducted in irrigation districts throughout California through the Energy Commission Agricultural Peak Load Reduction Program administered by ITRC, the average pump efficiency for pumps tested in irrigation districts throughout California was 57.5% (Burt and Howes, 2005).

Table 6: Average stated pumping plant efficiencies by pump category

	Deep Well Pumps	Surface Supply Pumps	Surface Drain Pumps	Overall Average	Number of Districts that did not know
Average Stated Pumping Plant Efficiency (%)	57	60	49	**55**	7

Source: Irrigation Training and Research Center

Age of Pumps

Figure 3 shows the age of the pump installations as a percentage of the total pumps in each category. This figure indicates that there have been few new surface supply pumps installed in the last two decades. However, there has been a significant number of groundwater wells installed recently and drain pumps installed between 6 and 25 years ago.

The recent increase in groundwater wells is due to the emphasis on conjunctive use throughout the state. The 5-year drought from 1989 to 1993 brought about a significant amount of new pumps since that time. The drought created severe surface water shortages, forcing districts to pump from the groundwater to supply water users.

In addition, districts have been encouraged over the past several decades to reduce the spill leaving district boundaries. Drain pumps have been installed to help recycle this water.

Rebuilt Pumps

The following table shows the number of pumps that the districts estimate are rebuilt per year. Also shown is the percentage of total pumps in each category rebuilt per year.

Table 7: Number of pumps the districts estimate are rebuilt per year

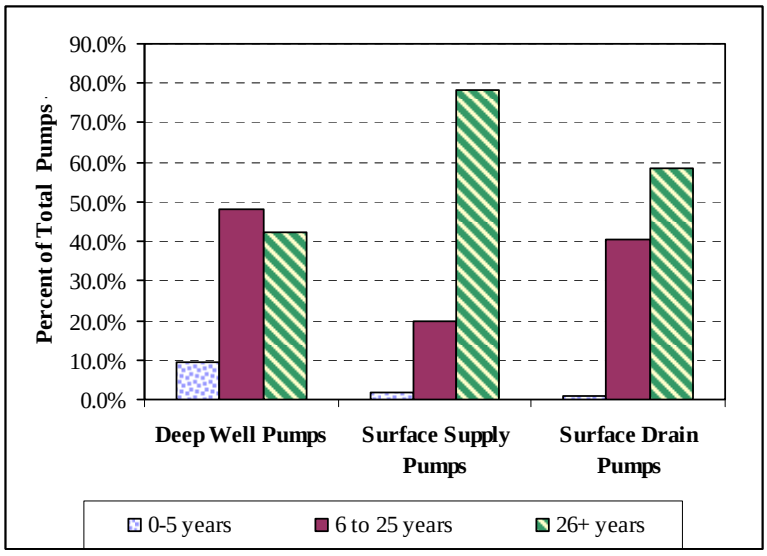
	Deep Well Pumps	Surface Supply Pumps	Surface Drain Pumps	Total
Number of pumps rebuilt per year	18	145	11	175
Percentage of pumps rebuilt per year	3%	12%	6%	9%

Source: Irrigation Training and Research Center

A higher percentage of surface water pumps are repaired. This may be because:

1. A higher percentage are older. (Figure 3)
2. Failure is more catastrophic to district operations than a pump failing in one of the other two categories.

Figure 3: Relative pump age for each pump category



Source: Irrigation Training and Research Center

Table 8 indicates different aspects that have been incorporated into district pumping operations. The last row shows the number of engines that are used by the 30 districts. Most of these engines are being used instead of electric motors because there is no electric service near the pump site.

Table 8: Aspects incorporated in the pumping operations

	Deep Well Pumps	Surface Supply Pumps	Surface Drain Pumps	Total
Total number of pumps repeated from Table 7	646	1,199	200	2,045
Number of				
premium motors	70	79	1	150
variable frequency drives	8	51	1	60
remotely monitored pumps	17	559	26	602
automated operations	59	615	48	722
remote manual on/off	0	504	0	504
diesel/natural gas engines	14	2	2	18

Source: Irrigation Training and Research Center

There are higher numbers of premium motors on deep well pumps, most likely because a higher percentage of the pumps are new (<25 years old) and the energy demands per volume of water pumped (e.g. kWh/AF) is typically much higher compared to the other categories. Therefore, the nominal increase in efficiency using the premium motor results in greater monetary savings with deep well pumping than with lower lift pumping.

Automation, variable frequency drives (VFDs), remote control, and telemetry seem to be applied mostly to surface supply pumps. This is expected because the surface supply pumps are the most critical when it comes to supplying water users. In most cases operations will not be significantly impacted if a drain or deep well pump fails. If a surface supply pump fails the results could damage crops in a large section of the district. The incorporation of automation and VFDs allow districts to operate their irrigation systems more consistently and with greater flexibility, providing their water users with improved service. In some cases VFDs have been installed so that pump bypasses can be abandoned.

Another possible reason for the high numbers of automated, remotely controlled and monitored surface water pumps is that districts have a significant number of pumps to operate simultaneously. Supervisory control and data acquisition (SCADA) systems (a broad term that incorporates telemetry, remote control/monitoring, and automation) have saved districts a significant amount of money and have reduced pollution by reducing the amount of time district personnel have to spend driving around to monitor and make adjustments (ITRC, 2002).

Annual Maintenance

The basic annual maintenance program is similar at every district and typically includes:

- Lubricating the bearings.
- Changing the oil (usually multiple times per year).

- Listening for vibrations and strange noises (typically daily or weekly).
- Making sure that the drippers on oil lubricated pumps are working (daily).

However, some districts have more advanced maintenance, as shown in Table 9. Some districts meticulously record volumes of water pumped and monthly energy usage for each pump station in the district (in some cases the districts use their SCADA systems to record actual amperage and flow rates in real-time). The districts trend this information to determine when a drop off occurs, which would indicate a problem.

A couple of districts utilize thermal imaging equipment to diagnose panel and motor problems as part of their annual maintenance program. Others have an electrician check their electrical panels for problems. Replacing the motor packing, or dipping and baking the motors, have been incorporated into regular programs for a couple of districts, although they do not do this to every motor each year.

Table 9: Some interesting maintenance tasks utilized by districts

Maintenance	Number of Districts
Trending flows and load over the year	8
Check electrical	8
Thermal imaging	3
Replace packing, or dip and bake motors	3

Source: Irrigation Training and Research Center

Table 10: Top 5 reasons for pump repairs (districts sometime gave multiple answers)

Reason for Repair	Number of Districts
Failure	15
Wear and tear	9
Low efficiencies	9
Vibration/balance/excessive noise	9
Drop off in production	6

Source: Irrigation Training and Research Center

Districts were asked if they had a power management program. This question was included to gauge how the district managers would respond. Most asked what "power management program" meant. Once it was explained that there was no specific definition, many managers outlined the type of energy-related management they conduct. The following items were commonly reported:

1. Recording and tracking monthly electricity records as well as pumping plant output and using these trends to make operational decisions
2. Participating in Demand Response Programs (ISO)
3. Tracking electrical loads in real time along with flow rates and water levels to get real-time pump efficiencies and making decisions on which pumps to run based on those with the highest efficiencies
4. Operating off-peak

Joint Power Authorities

Districts were asked whether they belonged to a Joint Power Authority. Currently there seem to be two major power authorities active among the surveyed districts. A third power authority that is not active is called the Southern San Joaquin Power Authority. The two active power authorities are:

East Side Power Authority (ESPA)

Members include:	Delano-Earlimart ID, Lindsay-Strathmore ID, Terra Bella ID, Rag Gulch ID, and Kern-Tulare ID.
Benefit:	Reduced power cost – Pool CVP power allocation then utilize it over a larger area (multiple districts). This allows the districts to purchase power when they need extra, or sell it when they have excess.

Power and Water Resources Pooling Authority – PWRPA

Members include:	Westlands WD, Glenn-Colusa ID, Banta Carbona ID, West Stanislaus ID, Provident ID, Princeton-Codora-Glenn ID, James ID, RD 108, Arvin-Edison WSD, Sonoma County W.A., Santa Clara Valley W.A., Lower Tule River ID, Byron-Bethany ID, The West Side ID, Cawelo WD
Benefit:	Pool energy resources (WAPA and project power) and distribute them among members to keep electricity costs down. The Authority can also buy and sell resources on the market to decrease power costs for its members. According to the PWRPA website, "The Power and Water Resources Pooling Authority (PWRPA) is a Joint Powers Authority comprised of 15 public water purveyors that organized in 2004 under California State law to collectively manage individual power assets and loads… Although principally formed to coordinate power supplies, these districts and agencies recognize the interchangeability of water management and power requirements; accordingly, as the name reflects, the participants envision alternative water-management options and potential exchanges as a potentially significant role for the Authority." (0Hwww.pwrpa.org)

Plans for the Near Future

For the survey, the "near future" was limited to the next five years. A number of districts have already installed all of the automation, SCADA, and VFDs that they feel are needed at least in terms of pumping. Other districts have no plans because of either limited budget or lack of interest. The lack of interest could be due to limited knowledge of how a specific technology could impact their district's operation. Overall, districts that have a significant amount of pumping are typically progressive when it comes to new technology because managers and boards are always trying to save their farmers money.

The following table lists the number of items the 30 districts surveyed plan on installing in the next 5 years. Real-time power monitoring and other SCADA system components are a significant portion of planned future investment. Districts understand the importance of operating at the highest possible efficiencies and the capability of remotely monitoring and controlling pump operations to ensure that the most efficient pumps are used.

Table 11: Planned improvements in the next 5 years – number of units involved

New Equipment Planned	Deep Well Pumps	Surface Supply Pumps	Surface Drain Pumps	Total	Number of Districts saying "Maybe"
Automation	1	90	43	134	2
Conversion to engines	0	0	0	0	0
Power factor improvement	0	0	0	0	2
Power monitoring (real-time)	221	95	42	358	4
Remote manual on/off	80	119	43	242	2
Remote monitoring	334	110	43	487	2
VFDs (new)	3	96	0	99	2
Well cleaning/maintenance	98	0	0	98	3

Source: Irrigation Training and Research Center

In general, the power consumption and load is expected to increase for these 30 irrigation districts. Some districts expect a drop in consumptive use because of increased urbanization or improved efficiencies. More districts, however, expect to increase both connected load and consumption due to increased cropped acreage, increase in permanent crops, and an expected need to pump more groundwater because of limited surface water supplies.

Table 12: Kilowatt and MWh change expected in the 30 districts over the next 5-10 years

	Deep Well Pumps	Surface Supply Pumps	Surface Drain Pumps	Total	Number of Districts Expecting Decreases (kW or kWh)	Number of Districts Expecting Increases (kW or kWh)
How much more **kW** in the next 5-10 years in each category?	41,914	9,811	270	**51,995**	3	22
How much more **MWh** in the next 5-10 years in each category?	381,000	7,500	0.0	**388,500**	5	20

Source: Irrigation Training and Research Center

At the same time that energy consumption is expected to increase, every district surveyed expects the electricity and demand charges to increase, though none attempted to estimate by how much.

Successful Past Projects

Table 13 lists interesting improvements that districts have implemented over the past 5-15 years in regard to pumping and electricity use. Many districts understand that there is a connection between water use efficiency on-farm and energy use by the district. They also understand that in many cases water use efficiency on-farm requires energy input from the farmer. However, water conservation is the main goal in most California irrigation districts – with a higher percentage than energy conservation.

Table 13: Innovative pump and electricity usage ideas implemented by districts

Description	Benefits
Joining a Power Authority (20 districts in the state; 10 of the 30 visited)	Estimated savings of $0.02/kWh
Adding solar, hydro, and natural gas generation	2-3 MW
Participating in the Energy Commission Ag Peak Load Reduction Program for Irrigation Districts administered by ITRC	
- *For Peak Load Reduction Grants*	- Over 15 MW of Peak Load Reduction between the surveyed districts - Over 20 MW of load in ISO demand response with APLRP assistance
- *For Pump Testing and Repair Rebates*	- 476 pump tests among 13 of the surveyed districts - 182 pump repairs among 10 of the surveyed districts
Encouraging farmers to go to off-peak pumping	Less on-peak power utilized
Improving water delivery service to farmers by installing float assemblies to maintain a constant water delivery pressure with variable pressures from the district pipeline and variable flow rates taken by the farmers	Shifting away from peak pumping as farmers begin utilizing off-peak water deliveries
Placing restrictions on the amount of tailwater leaving rice fields; districts provide incentives for farmers to put in a restriction at the end of their fields, limiting the flow of tailwater	Reduced supply water pumping as well as pumping of the drain water back into the system downstream
Installing SCADA and telemetry	Reduced operational spills, the time district operators must drive to physically monitor the system, etc.
Installing Variable Frequency Drives (VFD)	Saved energy due to VFDs installed to replace flow bypass and throttling valves
Encouraging on-farm water conservation through low-interest loans for improved irrigation systems and tailwater return systems	Grants provided by districts of up to $500 per acre and low-interest loans at around 3% interest for qualifying projects
Becoming operationally aware of energy demands and trying to minimize costs when possible	Reduced energy demands and on-peak load through better energy management

Source: Irrigation Training and Research Center

Conclusions

Common Answers

To complete the surveys, ITRC visited each participating district and asked the survey questions verbally. Most of the questions were discussion-based to encourage open answers (rather than multiple choice). The hope of the open discussion was to ignite innovative ideas and allow free, out-of-the-box thinking to develop. Even with open discussions, the districts' answers revealed trends in ideas and concerns. Some of these include:

Research Needs

- Time-of-use water meters
- Low-head hydro generation technology
- Solar generation
- Technical assistance on how to improve energy efficiency and reduce peak load
- More efficient pump impeller/bowl design
- Improved flow measurement in constrained areas
- Water conservation research and education at the district and farm levels

Policy Concerns

- Solar program grants are only for less than 1 MW of generation per meter
- SMUD does not accept irrigation districts for agriculture tariff
- Place-of-use restrictions are too strict
- Districts want more information about carbon credits

Grants, Rebates, and Low-Interest Loans

Since the Energy Commission APLRP for Irrigation Districts administered by ITRC ended in 2004, most districts surveyed have done minimal or no significant projects to reduce energy demands or shift load other than regular maintenance. Many of the districts that participated in the program now have new energy conservation and peak load reduction ideas but do not have sufficient funds to complete them. Ideas include:

- District peak load reduction (increase storage, pumping capacity, SCADA, etc.)
- Pump testing and pump repair rebates
- On-farm peak load reduction programs
- On-farm water conservation
- Solar rebates or grants

Current Status

Pump and electricity use characteristics of the districts surveyed are listed in Table 14.

Table 14: Summary of the pumping characteristics of the 30 districts surveyed

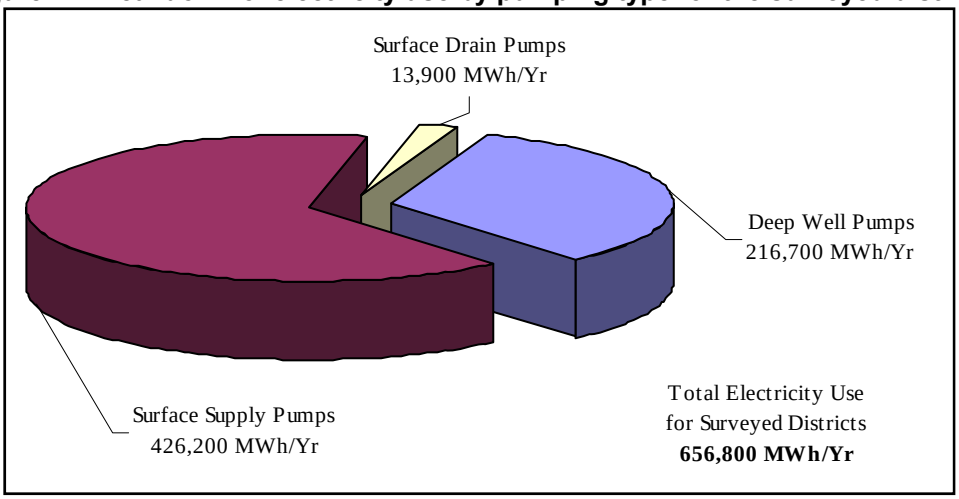
	Combined Total
Total Number of Pumps	2,045
Total Nominal Connected Horsepower (**HP**)	456,700
Total Average Electricity Use (**MWh**) per Year	656,800

Source: Irrigation Training and Research Center

Results from the survey indicate the following trends are common in participating districts:

- Figure 4 shows the breakdown for the pump categories discussed in the survey. Questions were asked regarding four pump categories: deep well pumps, shallow well drain pumps, surface supply pumps, and surface drain pumps. No districts claimed to utilize shallow well drain pumps, so these are not discussed.

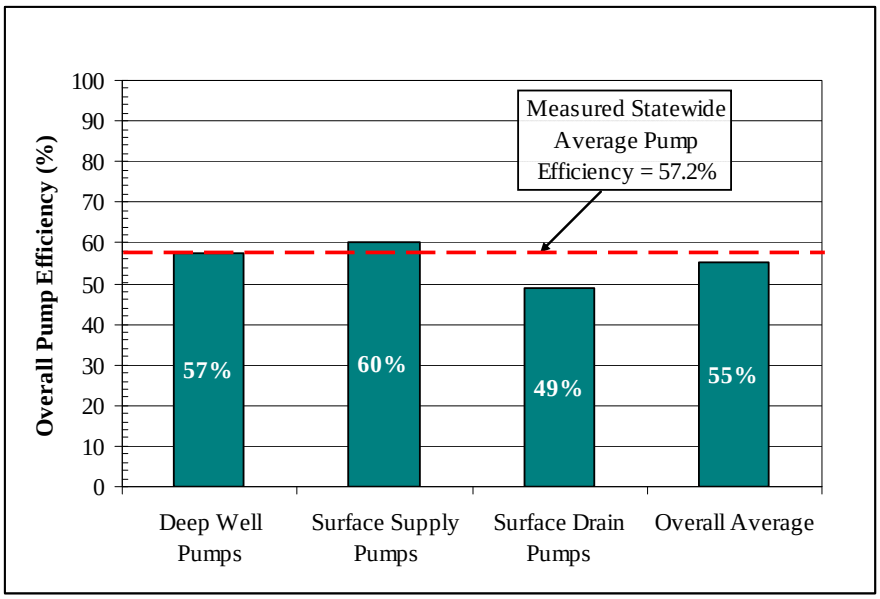
Figure 4: Breakdown of electricity use by pumping type for the surveyed districts



Source: Irrigation Training and Research Center

- Pump efficiencies stated by district personnel came out close to the overall average irrigation district pump efficiencies from over 1,100 pump tests conducted for the Energy Commission APLRP for Irrigation Districts (statewide pumping plant efficiency of 57.2 percent (Burt and Howes, 2005)). Not surprisingly, the stated pump efficiency for drain pumps was lower than the other categories (Figure 5). Most districts recognize that they focus more maintenance efforts on supply pumps because these are more critical from an operations standpoint.

Figure 5: District-stated pumping plant efficiencies



Source: Irrigation Training and Research Center

- One of the major unsolicited comments heard often during the surveys dealt with PG&E's service. A number of districts complained about how long it is taking PG&E to set up new service in the field. On average, it seems to take PG&E two years to establish a new connection from the time it is requested to the time it is completed.

- When asked for common day-to-day challenges regarding pumps, the most frequent response was keeping the pumps operational. It was not that the pumps or motors failed often; but when they did the results could be nearly catastrophic. The second most common answer was copper thieves stealing the electrical wire. This seems to be a significant problem for districts (at least those not utilizing 2,300 Volt service).

- When asked about future challenges the districts foresee, the most common answer was keeping pumping costs down.

Future Plans

Overall, the districts surveyed expect a significant increase in load and electricity needs in the next 5-10 years. In fact, nearly 75% of the districts surveyed expect an increase in load and electricity use. Some of the reasons for this expected increase include:

- Increased demand from permanent crops or increased crop acreage
- Increased groundwater pumping for conjunctive use or groundwater banking returns
- Districts taking over landowner wells

Some districts stated that they expected a decrease in load or energy use or both. Some of the reasons given included:

- Increasing pumping efficiencies
- Urbanization decreasing crop acreage
- Reconfiguring pumping systems
- Water conservation efforts by water users and districts

Table 15 shows the expected increase in connected load and electricity usage by the surveyed districts per year in 5-10 years.

Table 15: Expected increase in pump connected load and electricity use by the survey districts

	Total
How much more **kW** in the next 5-10 years?	51,995
How much more **MWh** in the next 5-10 years?	388,510

Source: Irrigation Training and Research Center

A number of the districts surveyed, especially those on the west side of the San Joaquin and Sacramento Valleys, expect increased crop demands from an increase in permanent crop acreage and in some cases an increase in overall acreage. Past studies conducted by the ITRC indicated that districts on the east side and middle of the two valleys are seeing a decrease in cropped acreage due to urbanization. It may be that farming is moving away from the lower areas that are typically gravity fed to higher areas that require increased pumping and typically have poor soils for growing crops. This is a significant event in terms of electricity demands in the future, as Table 15 indicates.

There are some basic conclusions that can be made from this survey:

- Districts throughout California share the stated goal of reducing power costs in any economical way possible.
- Electricity is on the forefront of operations and management concerns in most districts that require a significant amount of pumping. Interestingly, this is a relatively new development. Districts see no end to energy shortages. They are trying to minimize the impacts of future crises and the resulting increases in electricity costs. However, water conservation is considered more important than energy conservation.
- The districts have plans to reduce peak load and improve energy efficiencies but with limited budgets these will be slow to materialize. With incentives through grants, rebates, and low-interest loans these projects could be completed within a much faster time frame, providing benefits to not only the districts but also to the entire state. However, care must be taken to design these programs so that they are a benefit, not a hindrance, to the districts.

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TASK 2.2. CONVERSION TO GROUNDWATER PUMPING WITH DRIP/MICRO-IRRIGATION SYSTEMS

Chapter 1: Introduction

The Irrigation Training and Research Center at California Polytechnic State University, San Luis Obispo conducted this study on behalf of the PIER program within the California Energy Commission. This study was performed in the San Joaquin and Sacramento Valleys.

This study began by identifying the conjunctive use irrigation districts in the state. A "conjunctive use" district is one which uses both groundwater and surface water to supply irrigation needs. This list of irrigation districts was narrowed down to the districts that together contain 80% of the acreage in the survey area. This provided a feasible number of districts to visit to determine trends in drip/micro-irrigation and groundwater use. An initial email was sent to a representative of each district. A follow-up call was later made and the survey form was reviewed. In the majority of cases, a personal visit was made to each district to review data and district maps.

Overview of the Irrigation District Survey

A representative from ITRC contacted each district. The main question was: "How many acres in your district on drip/micro-irrigation do not use surface water even though it is available?"

Other questions were formulated to garner the reasoning behind the number of conversion acres, such as the relative cost of groundwater and district water, or the quality of the groundwater in the district's area.

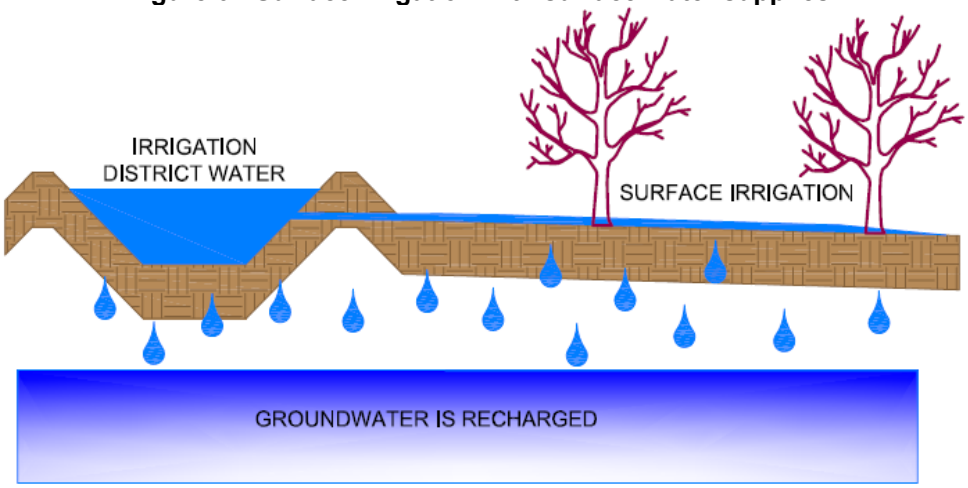
ITRC also asked about the quality of water delivery service flexibility, because different methods of irrigation require different water delivery flexibility. In some districts the tradition may be to provide water only once every 10 to 15 days for surface irrigation. However, such a low frequency of irrigation (once every 10-15 days) is not compatible with drip/micro-irrigation. Changing the flexibility of water delivery presents major modernization challenges for some districts, but has been undertaken successfully by many districts to encourage use of more efficient drip/micro systems.

Energy Implications of Drip/Micro Conversions to Groundwater

Figure 6 illustrates the general concept of irrigating using surface irrigation with surface water supplies. With this combination (surface water and surface irrigation), all the evapotranspiration requirement is met with surface water. Additionally, all or most of the deep percolation ends up in the aquifer and recharges the groundwater basin. In some areas, such as the eastern side of the San Joaquin Valley, the districts have historically delivered excess water to farms during periods of early spring runoff. By applying that excess water via surface irrigation, the districts were able to recharge the groundwater.

These irrigation systems often had little or no pumping costs other than occasional pumping costs by the irrigation district to deliver the surface water to the field turnout.

Figure 6: Surface irrigation with surface water supplies

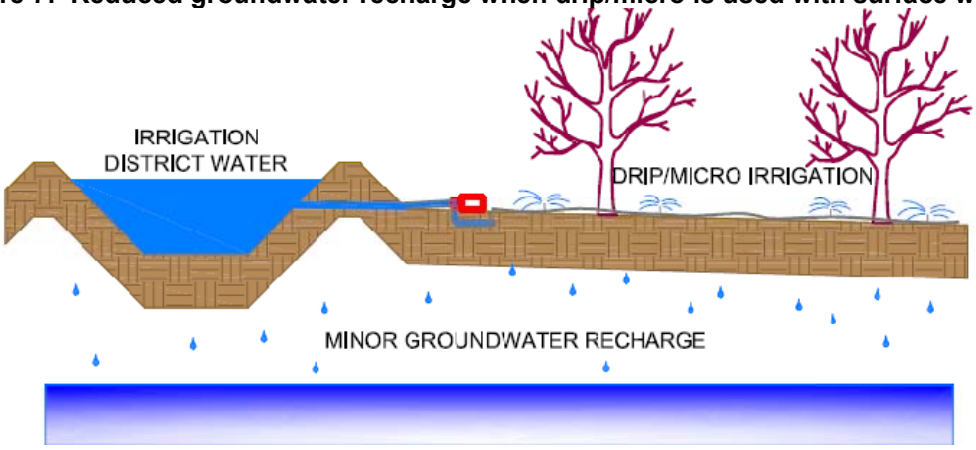


Source: Irrigation Training and Research Center

Over the past 30 years there has been a large shift to drip/micro-irrigation in California. Part of this shift is due to the fact that certain crops can be managed better (control of plant stress, fertigation) with drip/micro than with surface irrigation. The result has been increased yields and/or improved crop quality. Another reason for the shift is the relative ease of irrigating both small and large fields with drip/micro.

Figure 7 illustrates a scenario in which surface water is used for a drip/micro-irrigation system. In general (but certainly not always), farmers apply less water with drip/micro than with surface irrigation. Crop evapotranspiration rates tend to be higher under drip/micro than with surface irrigation. The net result is there is less deep percolation of water, which results in less groundwater recharge.

Figure 7: Reduced groundwater recharge when drip/micro is used with surface water



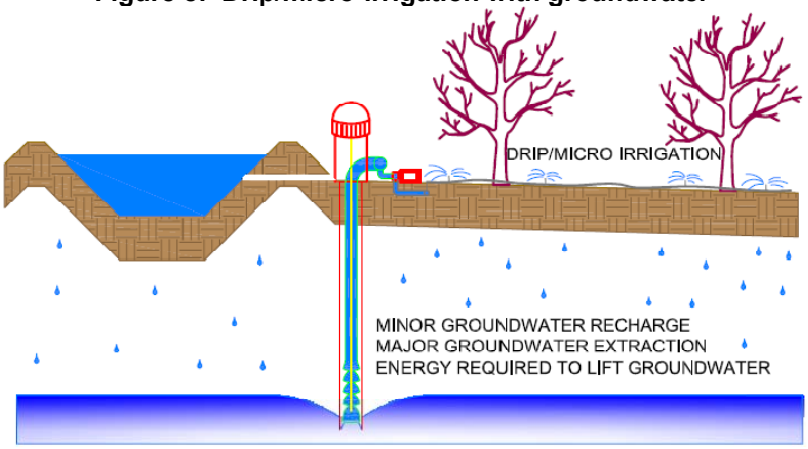
Source: Irrigation Training and Research Center

Figure 8 illustrates a groundwater-supplied drip/micro system. Under this scenario, groundwater levels take a "double hit" when growers convert to drip/micro-irrigation and continue to use groundwater, because water is extracted from the ground and not recharged.

The possibility of the groundwater table dropping becomes very likely. Energy consumption also increases with these conversions because of three factors:

1. Drip/micro systems typically require about 45 psi at the ground surface, just to operate the system.
2. A well pump is needed to raise the water to the ground surface.
3. Depleted groundwater results in increased lifts (over time) to the ground surface.

Figure 8: Drip/micro-irrigation with groundwater



Source: Irrigation Training and Research Center

"Conversion Acre" Definition

The focus of this study was to determine the number of "conversion acres" to identify changing trends in groundwater use. In order to be included as conversion acres in this report, the following must be true:

- A farm must have received surface water in the past from an irrigation district, or have easy access to surface water.
- The farm must be utilizing a form of drip/micro-irrigation.
- On a "normal year" (meaning normal rainfall and surface water supply) all of the farm irrigation water must come from the ground.

If a grower does not have the option to use surface water, but is using drip/micro-irrigation and groundwater, then that acreage was not considered to be "conversion acreage" because the grower's groundwater use has not changed.

Chapter 2: Basic Data

Of the 58 districts contacted:

- Twenty-one reported conversion acres.
- One district felt it did not have good enough information to participate.
- Thirty-six districts reported no conversion acres.

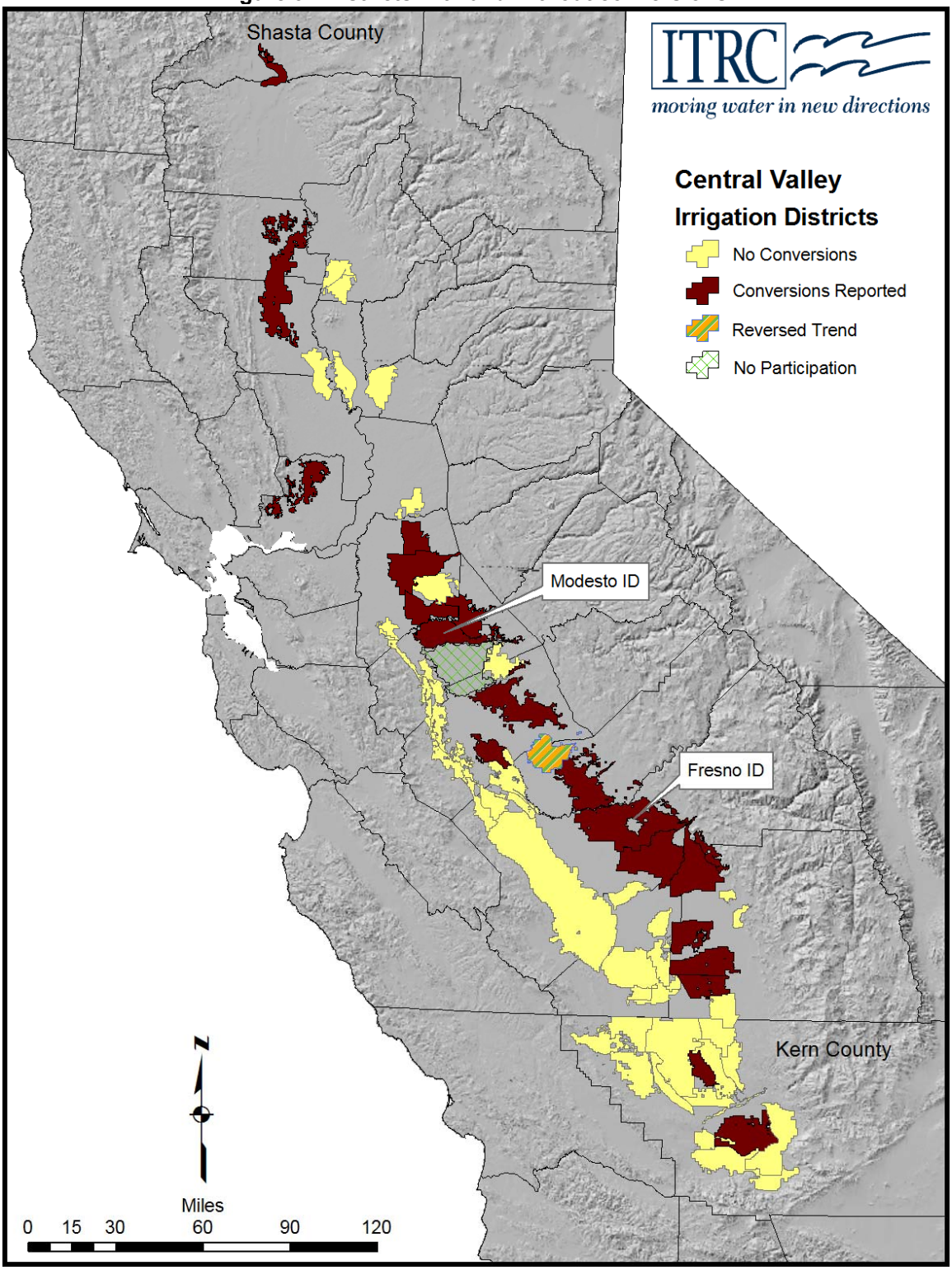
Table 16 and Figure 9 provide a summary of conversion acres in the selected districts. The only difference between these two views is that the GIS map does not show conversions by density or percentage of the district. It only shows if there were conversions or not. It is interesting to note that Figure 9 reveals that, in the San Joaquin Valley, most of the conversions are concentrated along the eastern edge of the valley.

Table 16: Districts Reporting Conversion Acres

District Name	District Size (ac)	Conversion Acres	Conversion Percentage
Fresno I.D.	247,786	9,000	3.6
Glenn Colusa I.D.	174,360	3,500	2.0
Consolidated I.D.	160,712	4,450	2.8
Merced I.D.	155,533	5,000	3.2
Alta I.D.	134,363	7,780	5.8
Madera I.D.	130,741	9,000	6.9
Kern Delta W.D.	128,720	960	0.8
Stockton-East W.D.	120,406	1,400	1.2
Lower Tule River I.D.	103,108	2,800	2.7
Modesto I.D.	102,143	1,925	1.9
Solano I.D.	78,070	960	1.2
Tulare I.D.	73,412	4,275	5.8
Oakdale I.D.	73,282	2,280	3.1
South San Joaquin I.D.	72,764	5,025	6.9
Pixley I.D.	69,865	1,930	2.8
North San Joaquin W.C.D.	53,313	2,400	4.5
Shafter-Wasco I.D.	38,930	100	0.3
Anderson-Cottonwood I.D.	33,404	3,610	10.8
Orland-Artois W.D.	31,450	2,830	9.0
Orange Cove I.D.	29,231	3,500	12.0
San Luis Canal Co.	47,500	490	1.0
Total	2,059,093	73,215	3.6 (wt. avg.)

Source: Irrigation Training and Research Center

Figure 9: Districts with and without conversions



Source: Irrigation Training and Research Center

Reasons for Not Converting Acres in Some Districts

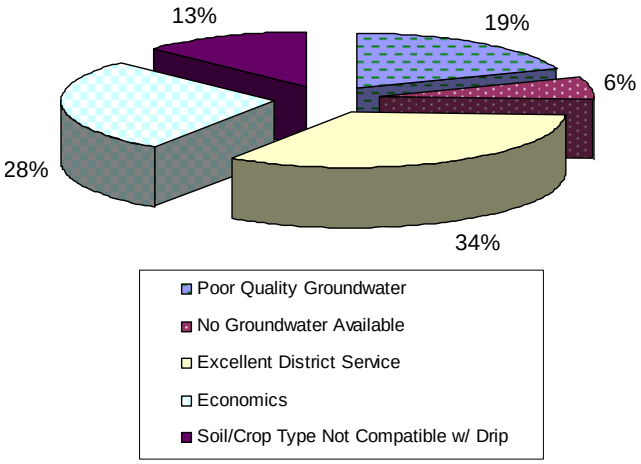
Thirty-six out of the 58 surveyed districts (62%) did not report any conversion acres. Each of these districts provided one or more reasons (Table 17) why their growers have not switched to groundwater:

- *Not possible to pump groundwater.* In this case, either there is no groundwater available or the groundwater quality is poor (usually too salty).
- *Excellent water delivery flexibility by the district.* This is the most common reason to not convert to groundwater on drip/micro-irrigation if groundwater is available. If a grower can obtain irrigation district water whenever he wants it with good service, then the growers typically do not feel a need to switch to groundwater.
- *Economics*
  - The district may have old and plentiful water rights (usually also meaning inexpensive surface water)
  - The groundwater may be extremely deep (and therefore expensive to pump).
  - The district may have already encountered a shift to groundwater, but has utilized billing strategies to encourage the use of surface water.
  - Some districts are short of water, so the growers all have well pumps anyway. These growers typically supplement groundwater with district water supplies (taking as much district water as they can get) regardless of irrigation method. There is, then, no "conversion."
- *The primary crop grown in the district is not compatible with drip* (e.g. rice). This is typically determined by climate, location and/or soil type.

Table 17: Stated reasons to NOT convert

Reason	Number[1]	% of Stated Reasons
Poor-quality groundwater	9	19%
No groundwater available	3	6%
Excellent district service	16	34%
Economics	13	28%
Soil/crop type not compatible with drip	6	13%

[1]The "number" adds up to more than 36 because several districts gave multiple reasons



Source: Irrigation Training and Research Center

Reasons to Convert to Groundwater

Twenty-one out of the 58 surveyed districts (36%), reported conversion acres. Table 18 provides a summary of the reasons to convert to groundwater. Each of these districts provided one or more reasons why their growers have begun switching to groundwater:

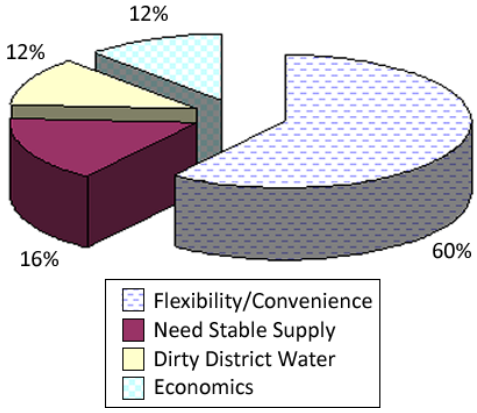
- *Grower convenience* (most common response). Many growers prefer to turn on a well pump instead of calling the district and ordering a specific amount of water. With a private well, a grower has ultimate flexibility and can automate the irrigation system so that no work is required except for an occasional checkup of emitters.
- *Uncertainty of surface water supplies in dry years* is a major problem for growers – especially those with permanent plantings. Depending on the districts' water rights, some districts may have access to surface water nearly all year long, while others may be limited to only a few weeks of water use on a dry year.
- *Water quality issues*. Many districts must deal with trash/debris removal from canals. In Merced Irrigation District, the trash/debris have grown to such a problem that growers were switching to groundwater to reduce filtration requirements. MID therefore began an aggressive technical assistance program to help farmers with good pre-filtration designs.
- *Economics*. This reason includes both the price of the water and the price of the infrastructure required to deliver that water. Drip/micro-irrigation requires prolonged duration and increased frequency, which is not compatible with some outdated district infrastructure and/or management practices. For example, some districts have small, concrete-lined farmer ditches that run a mile or more away from the canal to service remote fields. This works fine for surface irrigation. However, when the farmer converts to drip, he also needs to change this canal to an underground pipeline (a significant cost). From the farmer's point of view, the money may be better spent on a well and pump.

Table 18: Stated reasons to convert

Reason	Number[1]	% of Stated Reasons
Flexibility/Convenience	15	60
Need Stable Supply	4	16
Dirty District Water	3	12
Economics	3	12

[1] The total number of reasons exceeds 21 because several districts gave multiple reasons.

Source: Irrigation Training and Research Center



Case Study: New Almond Plantings

It is apparent that throughout California, the number of permanent plantings (mostly almonds) is increasing. This is important for this study, because nearly all growers who put in new fields of almonds or other permanent plantings will tend to use drip/micro-irrigation, and many of them will use groundwater for reliability and flexibility. When a grower invests in a new planting of almonds and drip irrigation, there is a huge upfront cost, not to mention operating costs, with no payback expected for nearly five years. Therefore, if growers suspect even a hint of insufficient water supplies from the district, they typically will choose to install a well to protect their investment. Since the groundwater well may be required for a reliable supply of water, and dual system hookups may be expensive (or confusing), the grower may just choose to not purchase the additional components that would create a dual system for occasionally utilizing surface water from the district.

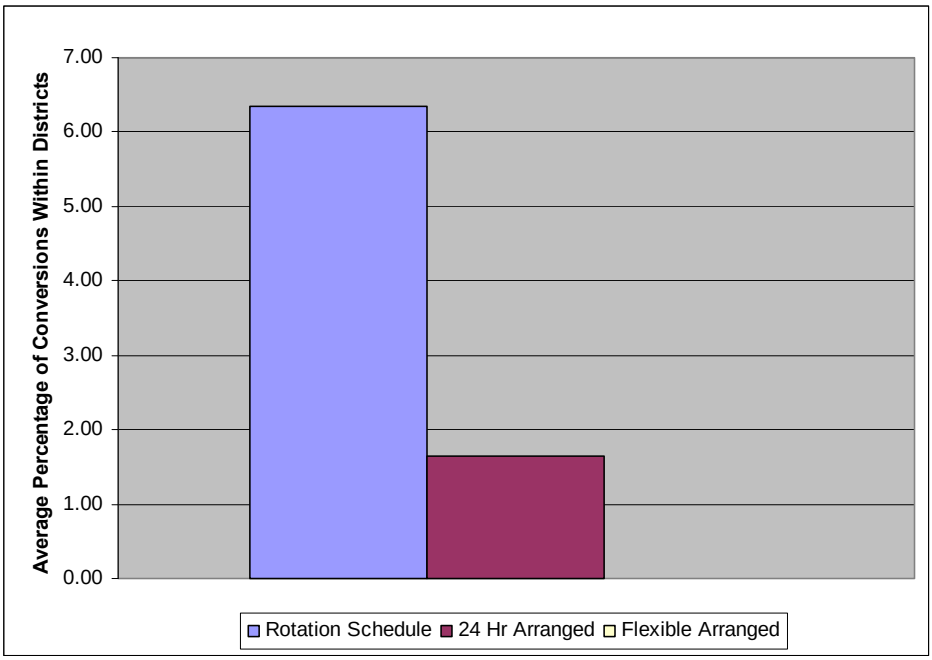
Chapter 3: Analysis of Survey Findings

District Delivery Flexibility

A lack of district delivery flexibility, combined with grower convenience (usually due to the convenience of autonomous pumps versus inflexible district delivery times), made up the largest reason for farmers to switch to groundwater use. Every district that reported a rotation delivery schedule (which is highly inflexible) to field turnouts also reported conversion acres. Conversely, every district that has modernized to a flexible arranged schedule has zero conversion acres.

Figure 10 shows how closely the district delivery flexibility is tied to the amount of conversion acres. This figure was created by averaging the percentage of conversion acres per district for each category of flexibility. The bar that would represent the flexible arranged schedule is missing from the chart, because there are zero conversions in every single district that has this high level of flexibility.

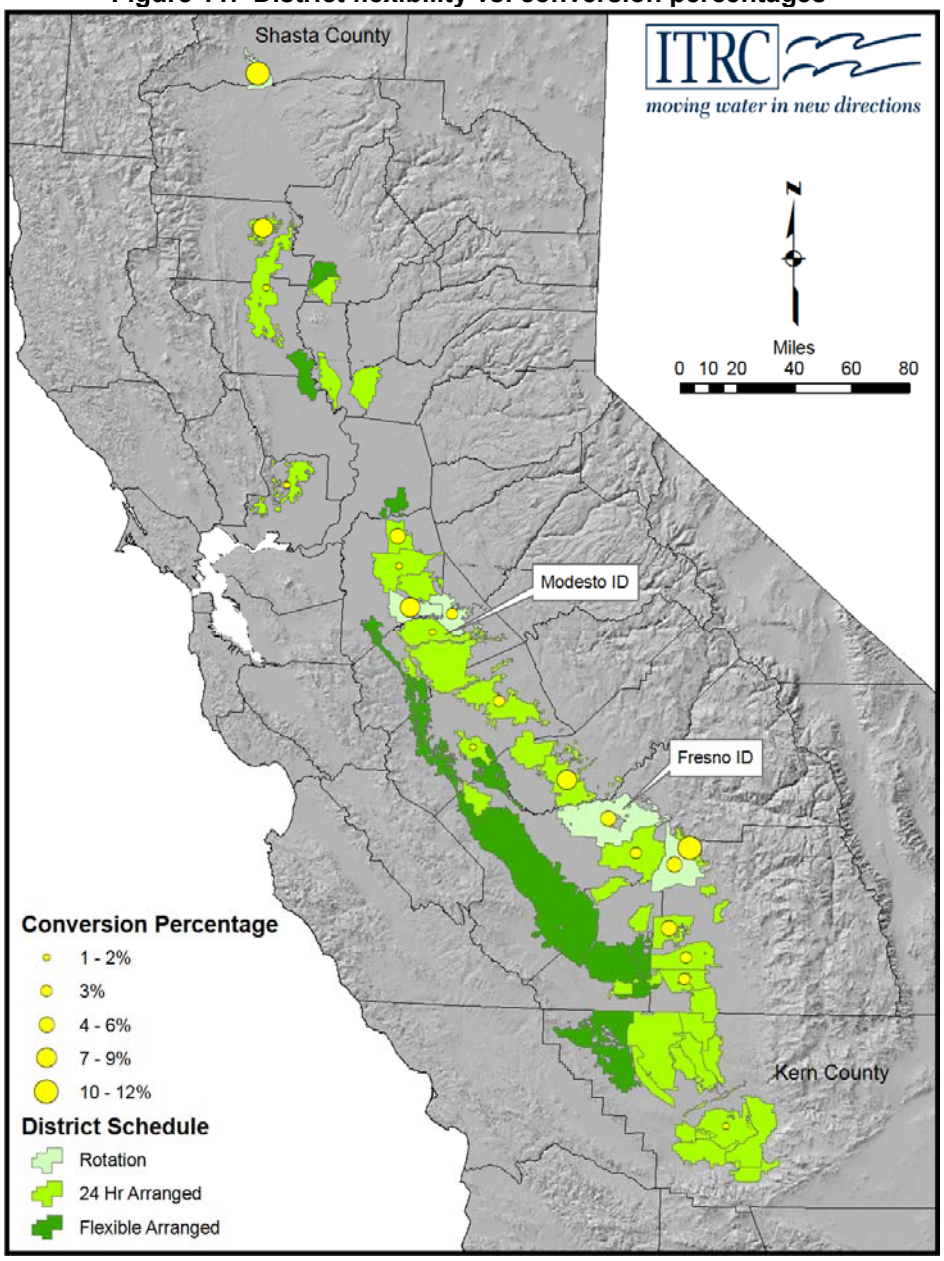
Figure 10: District water delivery flexibility (note that there are no conversion acres if a "flexible arranged" schedule is available)



Source: Irrigation Training and Research Center

Figure 11 provides a view of this same information on a map of California. This map shows each district and its delivery flexibility (by color), and the approximate location of conversion acres across the state. Each yellow dot represents the percentage of conversions in a particular district. The dots are typically concentrated in districts with either rotation or 24 hour arranged schedules.

Figure 11: District flexibility vs. conversion percentages



Source: Irrigation Training and Research Center

Economics

Initial Costs for Groundwater Pumping. One conversion hurdle for some farmers is the initial cost of drilling a well and buying the pump. Other farmers already have well pumps in place, so this is not a concern.

Quotes were obtained from pump dealers, based on recent installations of vertical turbine pumps in their area. The cost for a typical 450′ deep well with a 16″ casing is about $47,000 – although properly designed and developed wells can easily cost twice that. In short, a "typical" cost for a well plus pump is about **$100,000**. Detailed information is provided in Table 19.

Table 19: Information from pump dealers on recent pump purchases. Does not include the well drilling, casing, or development.

Quote #	Q, gpm	Setting Depth, ft.	HP	Material Price, $	Installation Price, $	Total Cost, $	$/HP
1	2000	300		55,000	5,000	60,000	
2	1500	350	250	60,000	5,000	65,000	260
3	2000	500	200	53,109	3,510	56,619	283
4	1500	380	150	41,256	4,500	45,756	305
Avg:	1750	382	200	52,341	4,503	56,844	282

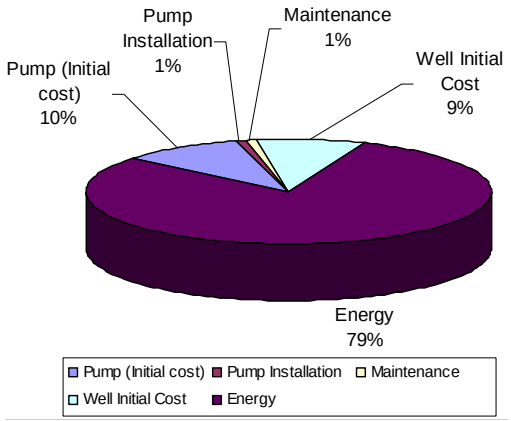
Source: Irrigation Training and Research Center

Annualized Groundwater Pumping Costs. Beyond the initial cost of a pump and well, it is interesting to examine annualized own/operation expenses. Figure 12 reflects information received from pump dealers.

Assumptions included:

- Power cost of 0.16 $/kW-hr
- Pump life = 25 years
- Well life = 40 years
- Maintenance interval = 10 years
- Interest rate = 7%
- 2000 hrs/year of operation
- Pumping plant efficiency = 50%
- TDH = 170′ (weighted average in the 21 districts with conversion acres)

Figure 12: Annualized groundwater pumping costs



Source: Irrigation Training and Research Center

Costs in Individual Districts. District and groundwater prices vary according to location. There are many irrigation water billing rates and billing methods across the state, and it is difficult to generalize them into one comparable number. However, irrigation districts typically charge for water in two ways (many districts use a combination of the two):

- Dollars per acre foot of water delivered (volumetric)
- Charges based on an assessment on the land – usually per acre of irrigable land

Table 20 shows an approximate comparison of groundwater versus surface water costs – excluding filtration costs for the surface water.

Table 20: Comparison of groundwater price vs. district water price for districts with conversion acres

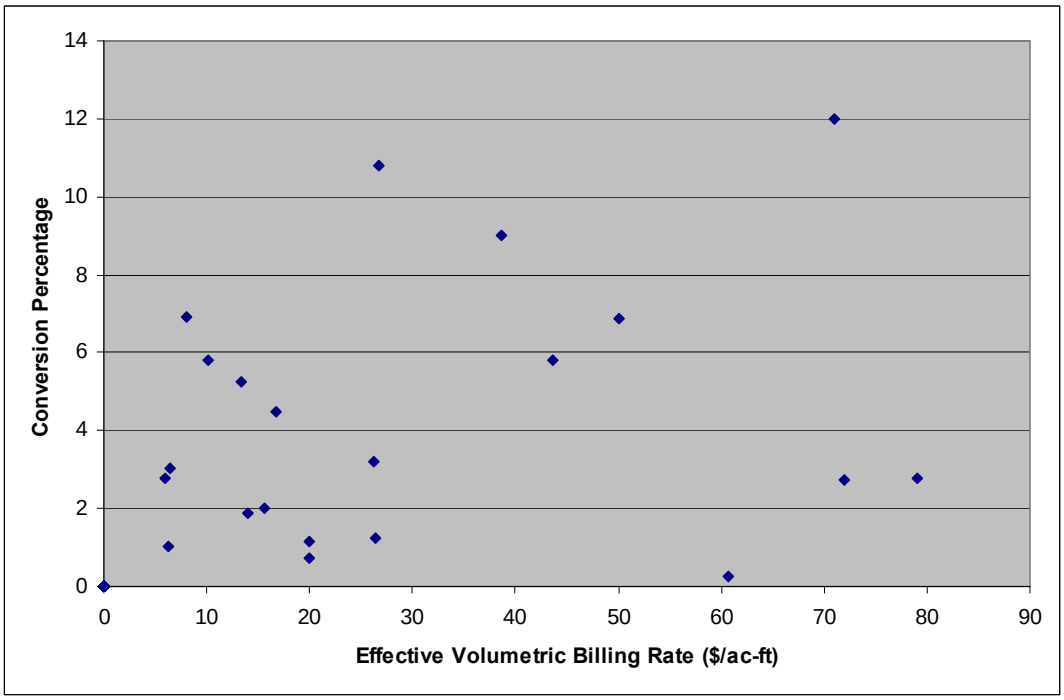
Irrigation District	Depth to Groundwater (ft.)	Approx. Groundwater Price ($/ac-ft)	Groundwater plus Annualized costs ($/ac-ft)	Reported District Water Price ($/ac-ft)
Alta I.D.	165	65	76	10
Anderson-Cottonwood I.D.	5	2	2	27
Consolidated I.D.	165	65	76	6
Fresno I.D.	170	67	79	13
Glenn Colusa I.D.	30	12	14	15
Kern Delta W.D.	270	106	125	20
Lower Tule River I.D.	115	45	53	72
Madera I.D.	160	63	74	50
Merced I.D.	50	20	23	26
Modesto I.D.	50	20	23	14
North San Joaquin W.C.D.	160	63	74	17
Oakdale I.D.	80	31	37	6
Orange Cove I.D.	360	141	166	71
Orland-Artois W.D.	125	49	58	39
Pixley I.D.	150	59	69	79
San Luis Canal Co.	350	138	162	6
Shafter-Wasco I.D.	270	106	125	61
Solano I.D.	120	47	55	26
South San Joaquin I.D.	150	59	69	8
Stockton-East W.D.	164	64	76	20
Tulare I.D.	120	47	55	44

Source: Irrigation Training and Research Center

Almost without exception, groundwater costs are greater than district (surface) water. It is possible that many farmers do not understand the true cost of groundwater pumping. However, if they do understand the difference in cost between groundwater and surface water, there must be reasons other than pumping costs to justify converting to groundwater.

Figure 13 compares the percentage of conversion acres to the cost of district water, to verify whether the cost of district water affects its use. The graph does not include the impact of groundwater pumping costs, but it does indicate that there is no uniform relationship between irrigation district water prices and conversion acres.

Figure 13: Conversions vs. water price



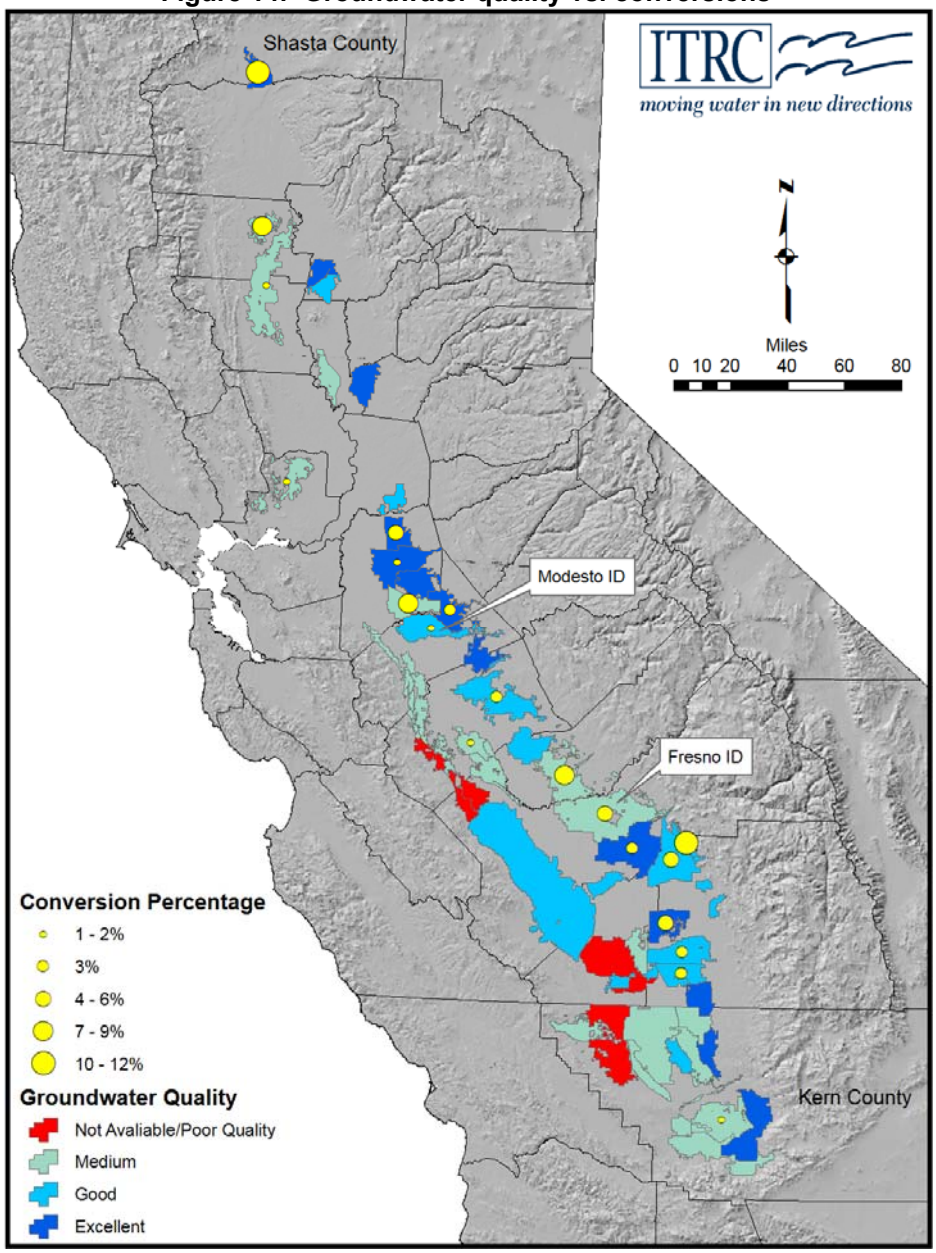
Source: Irrigation Training and Research Center

Some districts mentioned that if adequate supplies of both district (surface) water and groundwater are available, the price of the district water must be competitive in order to maintain customers on surface water. However, in districts with limited water supplies, district water may be quite expensive but farmers will still purchase the district water – especially in the case of poor or limited groundwater availability.

Groundwater Quality

Figure 14 shows the percentage of conversions in each district with a scaled yellow dot that represents the percentage of conversion acres in each district. In addition, the reported water quality of the district is represented by the color of each district. This map shows that districts with very low quality groundwater will not have conversion acres.

Figure 14: Groundwater quality vs. conversions

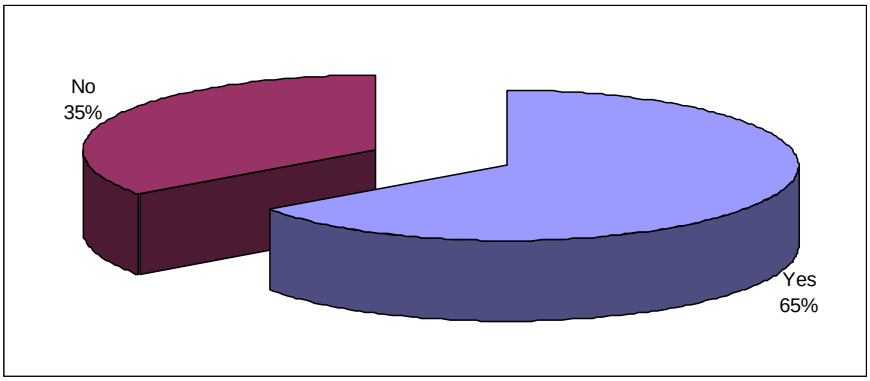


Source: Irrigation Training and Research Center

Chapter 4: Trends

Approximately two-thirds of the districts that reported conversion acres also indicated a concern that more acreage will be converted in the future (Figure 15).

Figure 15: Percentage of districts expecting future conversions (out of 21 districts reporting conversions)



Source: Irrigation Training and Research Center

Case Study: Fresno Irrigation District

Fresno Irrigation District (FID) is a large district. So large in fact, that the upstream and downstream ends of the district have completely different water delivery flexibilities to fields. During an irrigation season, water is always flowing through the canals at the upstream end of the district (because the required flow for Fresno ID is so large), while on the downstream end, water is delivered on a rotation schedule. Due to the layout of the district, the upstream end is effectively a flexible arranged schedule, while the downstream end is by default (and district policies) a rotation schedule. Therefore, there are no conversion acres in the upstream end of the district. Rather, they are all concentrated in the middle to lower end of the district. This reinforces the observation that growers who have flexible water delivery service have a low tendency to switch to groundwater.

FID is also perhaps the most at-risk district for large-scale future conversions. FID currently bills using only an assessment charge per acre of land in the district. Growers in Fresno ID currently pay the same amount to the district whether they take water or not, and no matter how much they take (they only have to wait for their turn in the rotation schedule). The combination of (i) per acre billing rather than volumetric billing, (ii) rotation delivery, and (iii) inexpensive water, encourages growers to stay with surface irrigation methods.

Fresno ID is considering a switch to volumetric billing. If this occurs, groundwater may appear to be a better choice for growers, since they cannot get “free excess” district water anymore. Some in FID estimate that as many as 60,000 acres could convert to drip/micro and groundwater if FID switches to volumetric billing without a corresponding improvement in water delivery flexibility. FID is beginning a modernization program to address the flexibility issue.

Summary

The acreage under drip/micro-irrigation will increase in the near and distant future. There is no single reason to switch irrigation methods, but reasons include perceptions of less labor, less fertilizer consumption, and higher yields and better crop quality.

Overall, there is a finite volume of irrigation district water available in the irrigated areas of California. From a water supply standpoint, one could legitimately ask if there is really an impact on water supplies if farmers switch to groundwater. The answer is "yes," but it is complicated. The major points are as follows:

- The volume of district-supplied water can vary tremendously from year to year. Therefore, irrigation districts depend on internal groundwater recharge during wet years. Although some irrigation districts have recharge basins, most of the districts depend upon over-irrigation with surface irrigation during the spring and early summer (when high runoff rates are available) to achieve much of the recharge. If fields are not set up for surface irrigation, this is problematic.
- If districts are unable to utilize these occasional very high flood flows for recharge, the water is "lost" to the ocean.
- If there is a major shift away from surface irrigation supplies, even during the summer months some irrigation districts may have difficulty selling surface water that is available. If that water is not used, it will be lost to the area – meaning that overall, the groundwater overdraft will accelerate.
- As urbanization increases, there are fewer good groundwater recharge sites available for irrigation districts to purchase as recharge ponds. This means that even if the districts would embark on large recharge projects, it may be difficult to implement them successfully because of the lack of good sites.
- Large acreages exist outside of irrigation district boundaries. These acreages depend upon groundwater only.

Impacts on Energy Consumption

More pumping energy is required for use of groundwater than surface water in almost all cases, with rare exceptions (e.g., Anderson-Cottonwood Irrigation District—due to the proximity of the district to the Sacramento River, the depth to groundwater there can range from 0-10 feet, and the energy required to pump is minimal).

Table 21 provides an estimate of the extra energy used per year on existing "conversion acreage." The total amount of energy spent on conversion acres (found in surveyed districts) is 75,962 MW-hr. However, the effect of rising conversion acres will only increase statewide energy consumption. This is evidenced because:

1. This study only includes 80% of district land.
2. If this trend continues in this way, the groundwater levels will drop. Therefore, everyone that pumps groundwater will use more electricity, including:
    a. The growers who are pumping groundwater (included in this report).
    b. All well pumps outside of district boundaries.
    c. Cities that rely on groundwater for their supply.

Table 21: Direct energy impact of existing conversion acres

District Name	Conversion Acres	Depth to Groundwater[1,2] (ft)	Groundwater Energy[3,4] (kW-hr/ac-ft)	Conversion Acre Energy/year (kW-hr)
Shafter-Wasco I.D.	100	270	663	198,886
San Luis Canal Co.	490	350	859	12,63,291
Kern Delta W.D.	960	270	663	1,909,301
Solano I.D.	960	120	295	848,578
Stockton-East W.D.	1,400	164	403	1,691,263
Modesto I.D.	1,925	50	123	708,990
Pixley I.D.	1,930	150	368	2,132,495
Oakdale I.D.	2,208	80	196	1,301,153
North San Joaquin W.C.D.	2,400	160	393	2,828,594
Lower Tule River I.D.	2,800	115	282	2,371,894
Orland-Artois W.D.	2,830	125	307	2,605,769
Glenn Colusa I.D.	3,500	30	74	773,444
Orange Cove I.D.	3,500	360	884	9,281,324
Anderson-Cottonwood I.D.	3,610	5	12	132,959
Tulare I.D.	4,275	120	295	3,778,825
Consolidated I.D.	4,450	165	405	5,408,034
Merced I.D.	5,000	50	123	1,841,533
South San Joaquin I.D.	5,025	150	368	5,552,221
Alta I.D.	7,780	165	405	9,455,901
Fresno I.D.	9,000	170	417	11,270,179
Madera I.D.	9,000	160	393	10,607,227
			TOTAL, kW-hr/yr:	***75,962,000***

[1] The depth to groundwater needed to be determined. One source for groundwater depth is the Department of Water Resources. ITRC also asked the districts for an average depth to groundwater in their area.
[2] To account for column losses, bearing friction, drawdown, and other losses, 20% was added to the groundwater depth to determine Total Dynamic Head (TDH).
[3] The overall pumping plant efficiency was assumed to be 50%, based on reported on-farm pumping plant efficiency.
[4] An average volume of water pumped per acre was 3 acre-feet.
Source: Irrigation Training and Research Center

Preventing an Increase in Conversion Acreage

District Modernization. Growers want flexible district service in order to accommodate the requirements of drip/micro-irrigation. The results of this study indicate that irrigation district modernization may be the best defense against drip/micro irrigated farmland converting to groundwater use.

Certainty of Surface Water Availability. Growers need a reliable source of irrigation water. Since surface water is sometimes unreliable (in a dry year), and it may be expensive to purchase and maintain the hardware for an irrigation system that uses both groundwater and surface water, some growers of permanent plantings will choose to utilize groundwater only. This shift to groundwater is a simple (albeit sometimes more expensive) solution if groundwater is available. Unfortunately, the present hydrologic status of California indicates that little will be done to guarantee stable surface water supplies.

Incentive and Grant Programs. The Energy Commission and other organizations can use incentives to encourage surface water use by growers who are on drip/micro-irrigation. These incentives should most likely come in the form of grants to irrigation districts for modernization. If the districts are able to update their infrastructure and operations, it will lead to better utilization of surface water on fields with drip/micro-irrigation.

Incentive programs may have unexpected consequences. An existing program that is worth mentioning is the Ag ICE program sponsored by PG&E. If growers sign up, PG&E will buy and destroy their old diesel engine, and then the growers are required to use a certain amount of electricity. This can unintentionally result in increased groundwater pumping, because the only way that the growers can use the required amount of electricity is to pump groundwater.

Successful Case Study: Chowchilla Water District

Chowchilla Water District has a critically over-drafted groundwater basin. The groundwater levels have dropped as much as 80 feet in the last 30 years in the Chowchilla area. This rapid drop in water levels was due to major new extraction that was occurring. When the district realized this problem, three things occurred to reverse the problem:

- The district adjusted its billing strategy to include an assessment charge of $40/ac that gets billed whether the growers take surface water or not. This revenue can be used to lower the volumetric rates on water or to implement new groundwater recharge projects. The effect of this billing strategy is to make district water use more attractive to growers. Also, the farmers tend to think that since they are paying for the water anyway, why not use it?
- Chowchilla Water District began a process of modernization. The first step involved switching from a rotation schedule to a 24 hour arranged schedule, which requires growers to call in and order water 24 hours before they take it. They are also working on increasing allowable flexibility for volume of water delivered and flow rate. The district modernization has included extensive buffer reservoirs, flow measurement, excellent water level control with long crested weirs and ITRC flap gates, plus SCADA.
- In addition to the above changes made by the district, growers began finding that they were spending more and more on electricity due to the dropping groundwater elevations. This increase in pumping costs has helped the problem to self-correct, by making it more obvious to farmers that there is a significant energy cost to groundwater.

Now, Chowchilla Water District does not report any conversion acres. The shift in water use has been reversed. However, the groundwater elevations do not appear to be rising. This is due in part to groundwater pumping by farmers outside the district. It is also due to the fact that the district cannot meet the peak summer demands of ET, so everyone has a well in conjunction with the surface water. The district water shortage will worsen if in the future more water must be released into the San Joaquin River for salmon run restorat

TASK 2.3. GIS-BASED IRRIGATION DISTRICT FLOW ROUTING/SCHEDULING

Chapter 1: Introduction

The Irrigation Training and Research Center of California Polytechnic State University, San Luis Obispo was contracted through the Public Interest Energy Research Program of the California Energy Commission to research the development and implementation of a GIS-based water scheduling and routing software system to aid California's irrigation districts in achieving their water management objectives. Additional funding for this research was provided by the California State University Agricultural Research Initiative (ARI).

Research Problem

There is typically a large amount of "art" (non-transferrable logic) involved in the decision-making of the managers/supervisors and field operations staff at a typical irrigation district regarding the approval of water requests, and the proper timing of flow changes at various control points in the canal system to ensure that flow changes arrive at farmer turnouts when promised. The intricacies of the district's operations are learned over many years by long-term staff members, who develop their own personal ways to manipulate water in the canal system. When those employees retire or leave, new employees usually need at least a year to learn how to properly operate canals. Furthermore, each new canal presents a new learning experience.

The research was proposed to evaluate the possibility of formalizing the experienced human decision-making process into a pragmatic software program to aid in the scheduling and routing of flows through canal irrigation distribution and delivery systems. It was recognized that there are complexities such as variable canal roughnesses, inaccuracies in flow measurement, unanticipated behavior of users, different types of canal structures that pass a flow change along the canal in different hydraulic manners, capacity limitations, etc. The conditions also change depending on the time of year.

Most irrigation districts are investing in GIS mapping of their distribution systems and combining their database systems to make information organization and analysis more efficient. GIS integrates spatial information about canal and pipeline infrastructure; facilities such as pumping plants and automated control gates; land use; customer accounts; time-series records; and other geographic data. GIS programs allow detailed characterization of a canal distribution system covering each node and segment (check structure and canal pool) in information (database) layers. However, there has been a technology gap in terms of enabling GIS-based databases to become fully coordinated with real-time decision-making within workflows for: (i) the scheduling deliveries of irrigation water (before the event), and (ii) dynamic, continuous adjustment and monitoring of various control structures and measurement facilities.

Project Goals

The objective of this project was to develop a prototype of GIS-based Decision Support System (DSS) software for scheduling and routing irrigation water in irrigation districts that would consider all information that is currently used by experienced personnel to:

- Receive water orders.
- Decide if sufficient total flow is available in the system to provide the requested orders.
- Decide if the canal system has sufficient capacity to convey the flow changes at the requested times.
- Determine when the water can be delivered.
- Create a "run sheet" that tells field operations staff when to make flow rate changes at different control points throughout the system.
- Transfer new setpoints directly to a SCADA system so that flow changes can be automatically made at the appropriate times.

Anticipated project benefits of the new software included:

- Conserved water – reduced operational spills
- Conserved energy – less recirculation pumping through better timing and control of the water
- Less reliance on "art" – less dependence on operators' historical experience, and more focus on a computer-oriented, knowledge-based decision-making system
- Improved water delivery flexibility – better service provided to the customers

Final Products

There were two distinct DSS software programs developed through this project:

1. **Irrigation District Scheduling** – Water Coordinator DSS (WCDSS). The WCDSS is a platform to assist office staff that receive water orders from customers, approve those orders, and then schedule flows in the main canal system to reach various off-takes for delivery laterals and direct turnouts at the designated times.
2. **Irrigation District Routing** – Lateral Decision Support System (LDSS). The LDSS is a platform to assist field operations staff that make physical manipulations to numerous control structures, monitor conditions on a real-time basis, maintain water records, and interface with customers.

Project Organization

Project Team

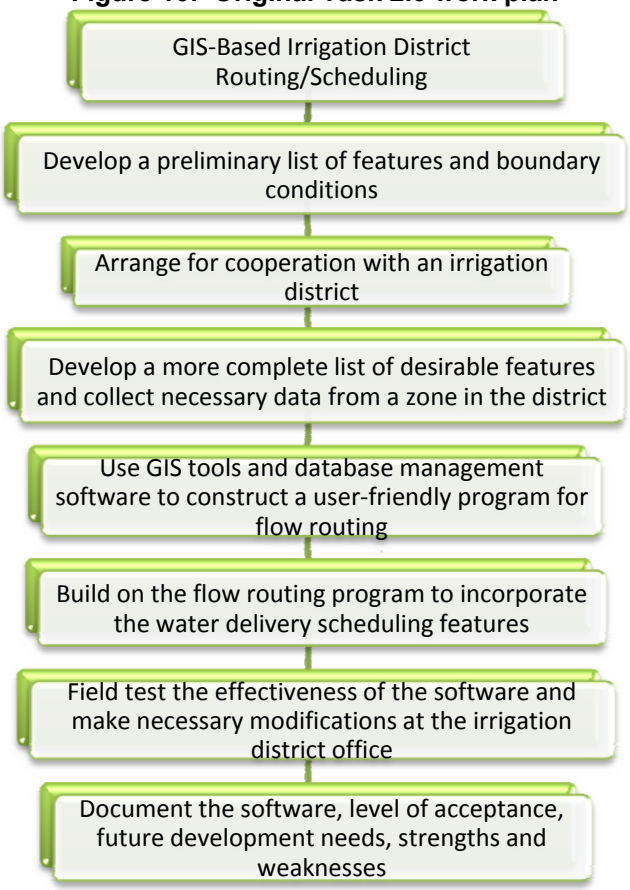
The role of ITRC in this research project was to define the conceptual framework, identify collaborators, coordinate project management, and provide irrigation-related technical expertise. Throughout the process of software development, demonstration, and evaluation, ITRC worked with several key cooperators:

- Imperial Irrigation District (IID) – provided the test location for piloting the software
- Davids Engineering – provided core datasets and IT support as the lead agency in the Efficiency Conservation Definite Team
- Keller-Bliesner Engineering – provided software application development, computer programming, and assistance with field trial evaluations
- TruePoint Solutions – consulted to aid in database compatibility

Development Plan

The original work plan for this research project is depicted by the flow chart shown in Figure 16**.**

Figure 16: Original Task 2.3 work plan



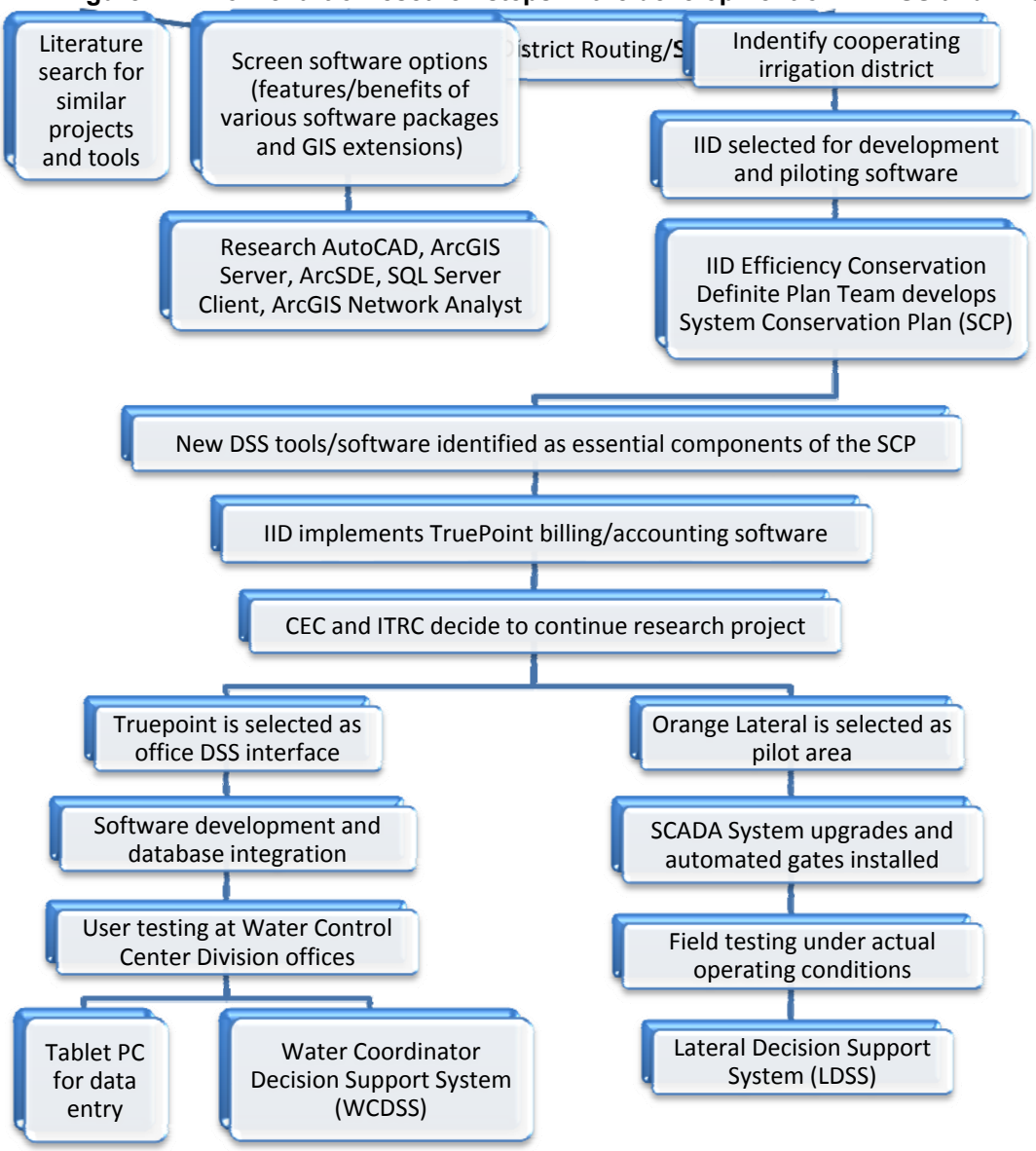
Source: Irrigation Training and Research Center

Several irrigation districts were initially identified as possible collaborators. As the project progressed, two of the three proposed districts (Modesto and Turlock Irrigation Districts)

determined that it would be several years until completion of their planned SCADA system and modernization upgrades. Imperial Irrigation District (IID) was selected as the appropriate agency for cooperating with the development and testing of the DSS software because IID had the prerequisite IT and SCADA backbone systems, and the research fit well with their water transfer program.

The actual sequence of work tasks carried out during this study is summarized by the flow chart shown in Figure 17. Refer to the following sections for a project schedule and decision timeline.

Figure 17: Flow chart of research steps in the development of WCDSS and LDSS



Source: Irrigation Training and Research Center

Project Schedule and Decision Timeline

In order to review the tasks that were accomplished for this project, the project timeline in Table 22 covers the major milestones within the framework of ITRC's initial conceptual

brainstorming in 2003 through to the implementation in 2010 of various DSS components in IID's Efficiency Conservation Definite Plan program. As is the case with most long-term projects as complex as this one, there was a significant amount of trial-and-error involved, meaning that numerous ideas were brainstormed and then tried out until the failed options could be eliminated.

Table 22: Project development and implementation timeline (2003-2010)

Date	Project Task
2003	ITRC begins initial development of the concept of water routing/scheduling software. The original concept involves integrating a routing/scheduling module into an industry standard GIS database.
2006	ITRC is part of the Definite Plan consultant team in Imperial Irrigation District (IID). ITRC has overall responsibility for developing strategic automation and modernization options for capturing canal spill and improving flexibility. The planning and demonstration efforts continue through 2009, eventually leading to the development of the System Conservation Plan (SCP), which incorporates various types of DSSs.
Jan 2006	ITRC holds discussions with computer modeling and water control experts from Holland on GIS-based DSS technologies for water management in irrigation districts.
Feb 2006	ITRC begins literature search for GIS-based water scheduling/routing projects and other DSS-related technologies that could have an impact on this project.
April 2006	ITRC reviews Colorado State University's use of MODSIM (a network solver for canal modeling purposes).
Oct 2006	ITRC conducts testing of magnetic flow meters (including the SeaMetrics AG2000 magmeter) in severely turbulent flow conditions. This SCADA-compatible technology was being considered for installation at all customer turnouts in IID.
Nov 2006	ITRC investigates specific commercially-available GIS extensions that may be applicable to the project, with assistance from a Cal Poly GIS instructor and industry experts.
Feb 2007	ITRC submits project proposals to ARI and Energy Commission (PIER) for development of GIS-based software for scheduling and routing irrigation water distribution systems.
Spring 2007	- ITRC brainstorms about software functional requirements and visual/diagram formats. - ITRC contacts various irrigation districts to obtain feedback on what type/format of information would best help them regarding scheduling/routing. - ITRC contacts Modesto ID and Imperial ID to determine the willingness of each one to participate, and assesses the potential application for a new DSS in conjunction with on-going modernization programs. - ITRC develops preliminary flow charts for information flow and decision-making logic.
May 2007	The Definite Plan team releases the final report for the IID Efficiency Conservation Definite Plan. The recommended package of system conservation improvements and management enhancements is collectively referred to as "Integrated Information Management" (IIM). A recommended short-term action is to pilot test IIM at the scale of at least one zanjero run.
Aug 2007	- ITRC continues to research software options, including ArcGIS extensions, and contacts GIS experts and database experts for feedback. - Initial contact with TruePoint representative about the feasibility of using their software as a basis for integrating scheduling/routing DSS components. - ITRC selects IID as the cooperating district due to synergies involved with their efforts in support of infrastructure improvements and management enhancements for a large water transfer program. - ITRC obtains permission from IID to utilize a lateral for testing and implementation of the scheduling/routing software. - ITRC creates a preliminary dataset to test anticipated program functionality using the family of ArcGIS programs and extensions. - ITRC studies building windows applications within the .NET framework. - ITRC re-evaluates the computational speed requirements of the proposed software in light of the high number of hydraulic and other types of calculations involved with each water request.

Table 22: Project development and implementation timeline (2003-2010) - continued

Date	Project Task
Sept 2007	- ITRC reviews a similar on-going program in Texas; meetings with project manager to assess their efforts. - ITRC brainstorms about programming, rules, database structure, inputs/outputs, etc. - ITRC compiles list of software options available with a detailed review of each option. - ITRC researches SQL server performance tuning.
Mar 2008	- IID implements TruePoint Solutions software for water ordering management, water billing, etc. - At the instruction of IID, the Definite Plan Team adds a new component to the IIM program to upgrade the existing SCADA system, including delivery scheduling and routing software. - Energy Commission and ITRC decide to continue with project in order to document efforts and the lessons learned. - The Definite Plan Team decides to utilize TruePoint's database as a foundation for the DSS programs. - A survey is carried out among IID division coordinators to define their priorities for making carryover decisions based on various times of the year. - Brainstorming meeting at Davis with all consultants involved with IIM. - Delivery and spill records are analyzed from a variety of canals in IID in order to select a canal for the pilot demonstration of various planned DSS software packages. - IID suggests several laterals within the Orchid Run for the test location.
Apr 2008	- ITRC and Davids Engineering ride with zanjeros to learn about operational rules/procedures. - The Orchid and Holt zanjero runs are selected for testing of improved lateral operation. - The Orange Lateral is selected for delivery gate (turnout) automation and improved measurement.
May 2008	ITRC begins field testing various options for laptops, SCADA HMI software, etc.
June 2008	- Links refined between TruePoint database and proposed scheduling/routing databases. - Data requested from IID in order to begin testing/programming. - TruePoint hired as programming consultants to help with database compatibility (between their existing database and our proposed project). - ITRC proposes "Human SCADA". Zanjeros would function as the information collectors/updaters to provide current real-time information on gate position changes, etc. This would save money but would rely heavily on accurate timely information from zanjeros. - Keller-Bliesner Engineering creates an initial version of a flow chart for WCDSS software and the water ordering/scheduling process. - **Major Decision**: the project is formally organized into two distinct DSS components: • LDSS software – to be used by field operations staff • WCDSS software – to be used by office staff
July 2008	- ITRC personnel ride along with zanjeros in the Orchid run. - Final versions of flow chart of WCDSS software and water ordering/scheduling process decided on by Definite Plan Team. - Remote internet options researched. - Literature search for other channel automation projects performed.
Aug 2008	- Installation of the SCADA hardware for the pilot automated turnouts starts in the Orange Lateral. - ITRC personnel spend time with Water Coordinators to ascertain how water orders are received and processed in the office. - Keller-Bliesner Engineering starts formal programming of WCDSS software. - Keller-Bliesner Engineering and Davids Engineering visit water coordinators to discuss WCDSS work in progress and observe/document the current process used in determining carryovers.
Sep 2008	- ITRC begins research to solve data entry issues for water orders. - Cal Poly Computer Science student hired to work on the optimization problem for WCDSS decision making.
Nov 2008	- ITRC organizes information on wave travel time for LDSS software. - ITRC develops several prototype ClearSCADA screens for LDSS software. - ITRC obtains tablet PC and Active Ink software for testing. - Active Ink hired to customize water ordering form.
Dec 2008	- IID Water SCADA Dept. begins work on creating LDSS ClearSCADA screen and programming logic. - Phase 1 of the evaluation of the Orange Lateral pilot is carried out.
Feb 2009	Work continues on improving handwriting recognition of tablet PC, but it cannot be improved to satisfactory levels. Tablet PC sub-project abandoned.
Mar 2009	The IIM plan was re-formulated by the Definite Plan Team to reallocate funds away from automated turnouts and toward more system conservation hardware projects. IIM is renamed the System Conservation Plan (SCP).

June 2009	Phases 1 and 2 of the Flow Rate Verification evaluation report of the Orange Lateral are completed (based on a total of 69 field tests).
Sep 2009	Keller-Bliesner Engineering pilots the draft version of the WCDSS software with the IID office staff at Division offices.

Table 22: Project development and implementation timeline (2003-2010) - continued

Date	Project Task
Oct 2009	IID suspends implementation of the WCDSS based on negative feedback from Water Coordinators.
Nov 2009	ITRC hosts a SCADA tour for IID water managers to visit irrigation districts in the San Joaquin Valley to learn about different approaches to automation, using various DSS tools, and implementing SCADA.
Dec 2009	The Definite Plan finishes the System Conservation Plan. The series of final reports include: conceptual engineering designs for $215 million of infrastructure improvements; a district-level operations plan; SCADA system specifications; specifications for turnout flow measurement devices; and a development plan for the Water Operations DSS.
Spring 2010	The LDSS components continue to be incrementally improved and used for operation of the Orange Lateral.
July 2010	Keller-Bliesner Engineering begins to pilot test the Water Operations DSS for the main canal system.
Sept 2010	ITRC prepares this final report for Energy Commission/ARI.

Source: Irrigation Training and Research Center

Several points can be made from the project timeline outlined in Table 22 above including:

- ITRC had been brainstorming and investigating the concepts of a DSS package for irrigation districts for several years before this project started.
- A rough estimate is that there were at least 100 working meetings held since 2007.
- The development of the DSS software components involved a multi-disciplinary team of engineers and scientists with expertise in irrigation districts, advanced automation technologies, database programming, GIS, operation of canal systems, and mathematical optimization, as well as numerous staff of a large irrigation district.
- It took over a year of active brainstorming to define the desired functionality and performance requirements of the proposed DSS software.
- Field evaluations of the piloted LDSS were conducted for over a year.
- The development of the package of DSS tools proceeded in tandem with the design and planning of infrastructure projects that involve a large amount of SCADA and automation.
- The formulation of the DSS software components benefitted from the extensive interaction with field operations staff, who helped greatly to tailor the usability of the tools.
- Despite a long-planning effort and extensive consultation with IID staff during the development of the WCDSS, it only took several weeks of an unsuccessful trial by the Water Coordinators for the district to indefinitely suspend use of the program.
- Even though the core of the DSS effort was a software-centered exercise, the actual work tasks were heavily based around hardware components (turnout gates, laptops, flow measurement, canal hydraulics, etc.).

Chapter 2: Water Coordinator Decision Support System

Purpose and Background

ITRC initially envisioned DSS software tools that would assist irrigation districts with two basic tasks: (1) scheduling water orders in the office based on requests from customers, and (2) routing irrigation water through a complex network of canals, reservoirs, recirculation pumping plants, etc. This chapter covers the first task – irrigation district scheduling – and how that led to the development and testing of the Water Coordinator DSS (WCDSS) at IID.

Water Coordinators in the Division offices are the primary people responsible for interacting with IID's customers who call the office to place an order for water or to make changes to an order that has already been placed.[1] The main decisions that the Water Coordinators must make are which water orders to fill, and which to carry over (a "carryover" is a water order that could not be delivered on the requested date due to unavailable capacity in the system, water supply shortages, or other reasons).

If there were enough water and enough capacity to fill every order, then there would be no decision to make. Unfortunately, this is rarely the case. The majority of the time, the Water Coordinator must rely on his/her experience and personal interpretation of a set of standard criteria to make these decisions. For example, the type of crop being irrigated is one criterion that is considered by the Water Coordinators – certain crops such as vegetables get a higher priority because they are more sensitive to stress if the timing of irrigation is delayed. Some of the carryover variables to be considered when scheduling water orders include:

- Capacity constraints (related to time of year).
- Basic information
  - Number of days of delivery requested
  - Has it already been carried over?
  - Crop type.
- Shifting on/off sequence for achieving a semi-rough hydraulic balance (is someone turning off at approximately the same time someone else wants to turn on?).
- Number of days that each farmer has been carried over this year.

When these variables have to be manually analyzed for each individual water order, considering the vast number of delivery gates and customer accounts in IID, the decision-making process is cumbersome and prone to uneven execution.[2] None of the water ordering decisions could be made instantaneously because Water Coordinators only have enough time when speaking with the customer to jot down information about the order and then answer the next telephone request. Therefore, the district has to use a batch ordering process, meaning that the distribution of carryovers has had to be analyzed manually after a designated period in the morning.

[1] There are approximately 30 Water Coordinators for all of IID's Division offices.
[2] There are approximately 5,000 customer water accounts in IID.

In addition, even though the district has invested heavily in various IT and SCADA technologies over the years, many of the steps in the water ordering process, before this project, were done manually, and almost all the information between IID staff in different offices was shared via telephone.

During the duration of this study, IID was relying on several different practices:

- The Division offices already had access to real-time and historical data from the district's extensive SCADA system and other core databases such as the Water Information System (WIS).
- In 2008, IID purchased and implemented the TruePoint Solutions package of water ordering and billing software. IID began using TruePoint as its central database software platform for water scheduling in March 2008 as part of an effort to streamline water ordering and billing. However, TruePoint software does not include any explicit functionality for handling carryovers.
- Even after the implementation of TruePoint, office staff still had to manually check canal capacities and compare them to requests for water in different amounts and at different times, and then manually rank each water order relative to a number of other criteria.

The objective of the WCDSS, therefore, was to create a new software tool that could be tightly integrated with TruePoint in order provide specific information related to carryovers. The purposes of the new DSS tool were defined as:

1. Provide a list of "approved" water orders
2. Provide a list of carryover water orders

Thus, while water orders would continue to be entered into TruePoint, the new DSS tool would be a stand-alone software package that would compare the quantity (CFS) and timing of the water order with three (3) different sets of parameters that reside in different places within the greater IT system(s) at the district:

1. Design canal capacity
2. Current flows in the system
3. Carryover rules

This is especially challenging because actual water *deliveries* (as opposed to *orders*) do not usually follow the pre-programmed schedule for a variety of reasons. Changes are being made continually, 24 hours a day. This means that the actual flow rates in various canal pools at the time of allocation decisions may not be what the people in the office think they are. Because of this, the Water Coordinators had the authority to intervene and give final approval to the scheduled line-up of orders.

With WCDSS, Water Coordinators can do the following:

- Select rules for making decisions about carryovers
- Over-ride suggested water schedule line-ups, if necessary

- View canal capacities (based on roughness at different times of year and channel dimensions)
- View a GIS model of the district/lateral
- Automatically update the TruePoint database so that an order sheet can be printed for the zanjeros

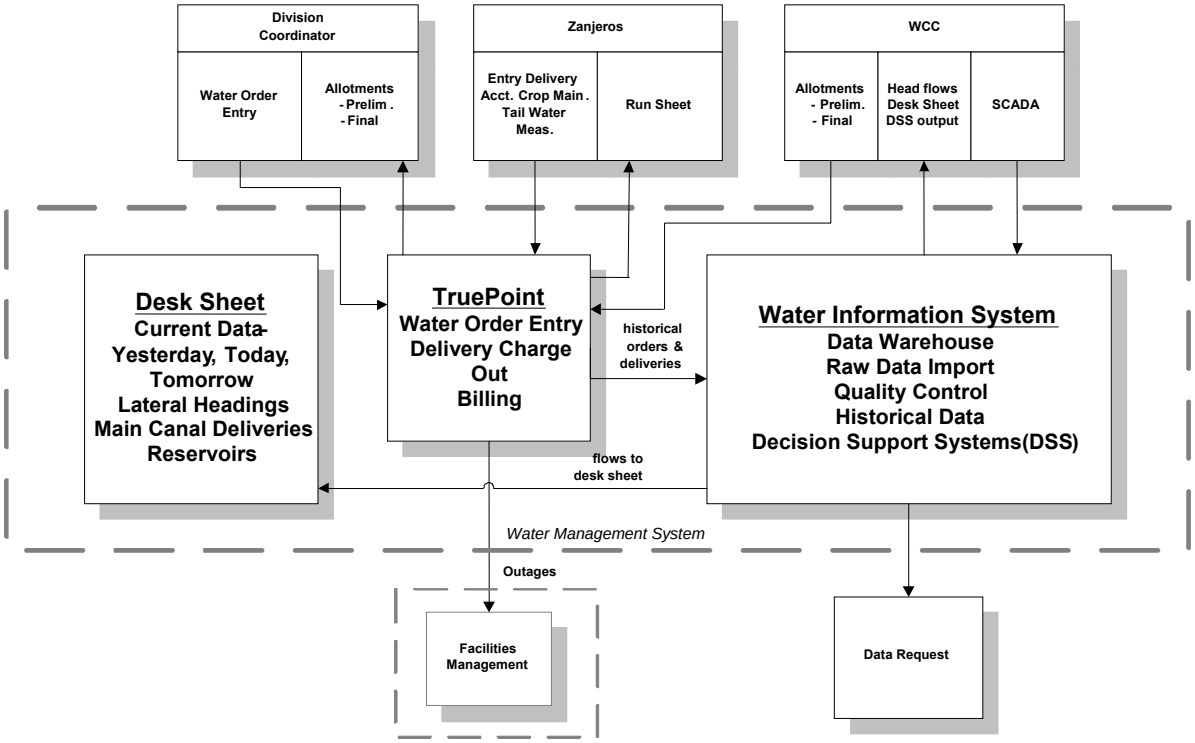
ITRC was closely involved with formulating the decisions and rules that were used to develop the WCDSS software. Keller-Bliesner Engineering was responsible for programming this software package. The *WCDSS Software Documentation and User's Manual* is provided in Appendix 2A.

Integration with TruePoint Software

Given the sophisticated nature of IID's existing IT system(s) and database structure(s), in addition to the advanced database that resides within the TruePoint software, the integration of the WCDSS tools had to be carefully tailored considering factors such as the very large number of discrete data points, multiple users who are distributed among offices in different locations, the required computational speed, security, and networking topology (refer to **Figure 18**).

Figure 18: IID Water Management System showing inter-connections of TruePoint software

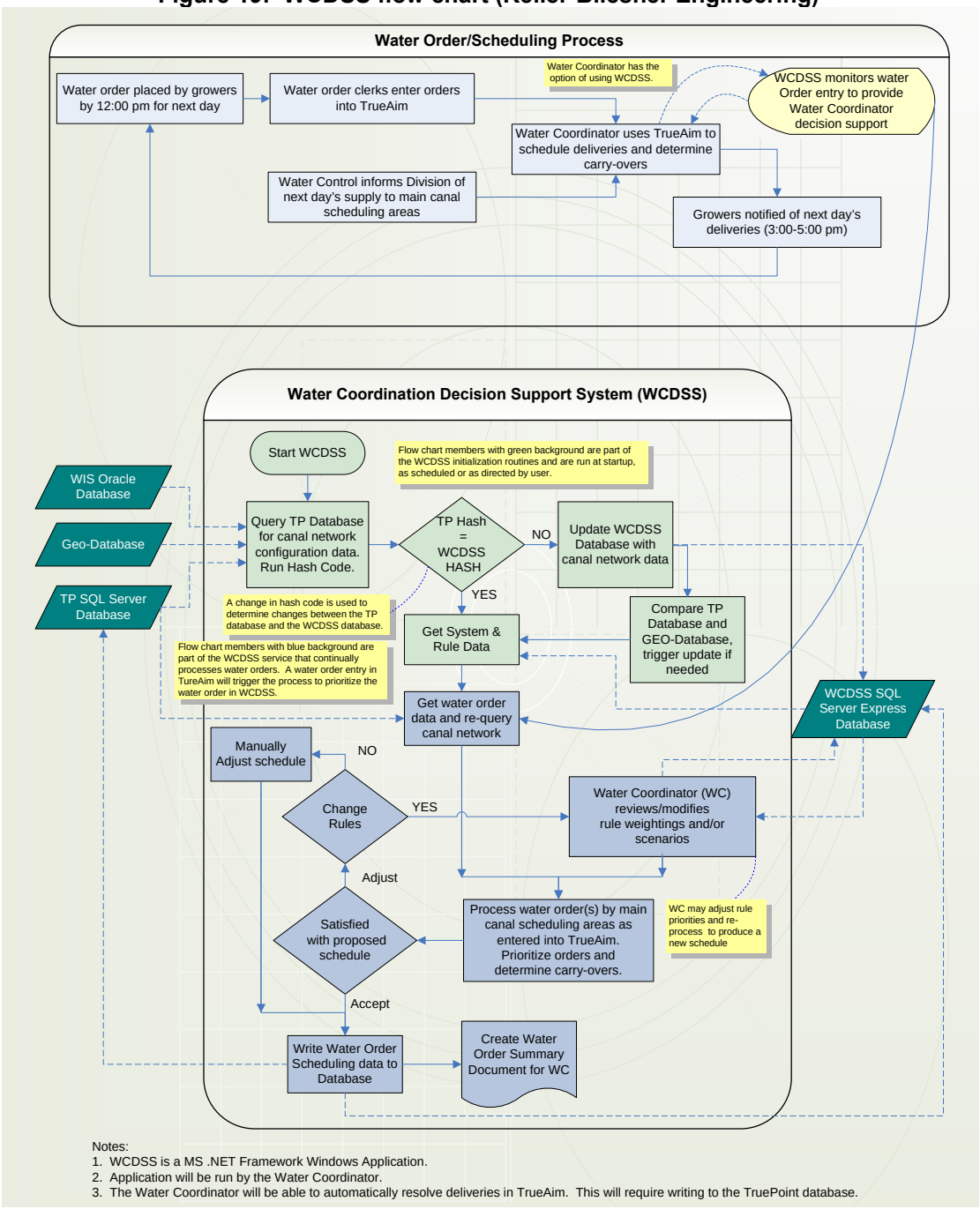
IID Water Management System



Source: Irrigation Training and Research Center

The operational flow chart of the WCDSS integrated within IID's IT database systems is shown in Figure 19.

Figure 19: WCDSS flow chart (Keller-Bliesner Engineering)



Source: Irrigation Training and Research Center

The TruePoint software accepts daily water orders and assigns them by geographic location. The program contains a GIS map that keeps track of which turnouts are located upstream and downstream; where laterals connect with each other or a main supply canal, etc., so that the new water order information can be combined with the existing delivery information and positioned within a GIS network representing the entire water distribution system.

About 20 irrigation districts in California have implemented various components of the TruePoint software package as of the time of this report. However, the TruePoint software is a standardized program and is not customized for applications at each irrigation district. This means that in the case of IID, even though the Water Coordinators had the ability to enter water orders into the system with a date/time scheduled in the future, they still had to follow the same manual process for determining which orders were to be carried over.

Operation of the WCDSS

WCDSS is a stand-alone Microsoft Windows® application based on .NET Framework technology. The WCDSS is installed on a user's workstation (office desktop computer), and accesses external data sources such as the TruePoint database via SQL Server and SQL Server Express. The process of retrieving water order information from TruePoint and bringing it into the WCDSS environment is called "transactional replication." These SQL tools and other networking tools provide a seamless mechanism for synchronizing water ordering information back and forth between the TruePoint database and WCDSS.

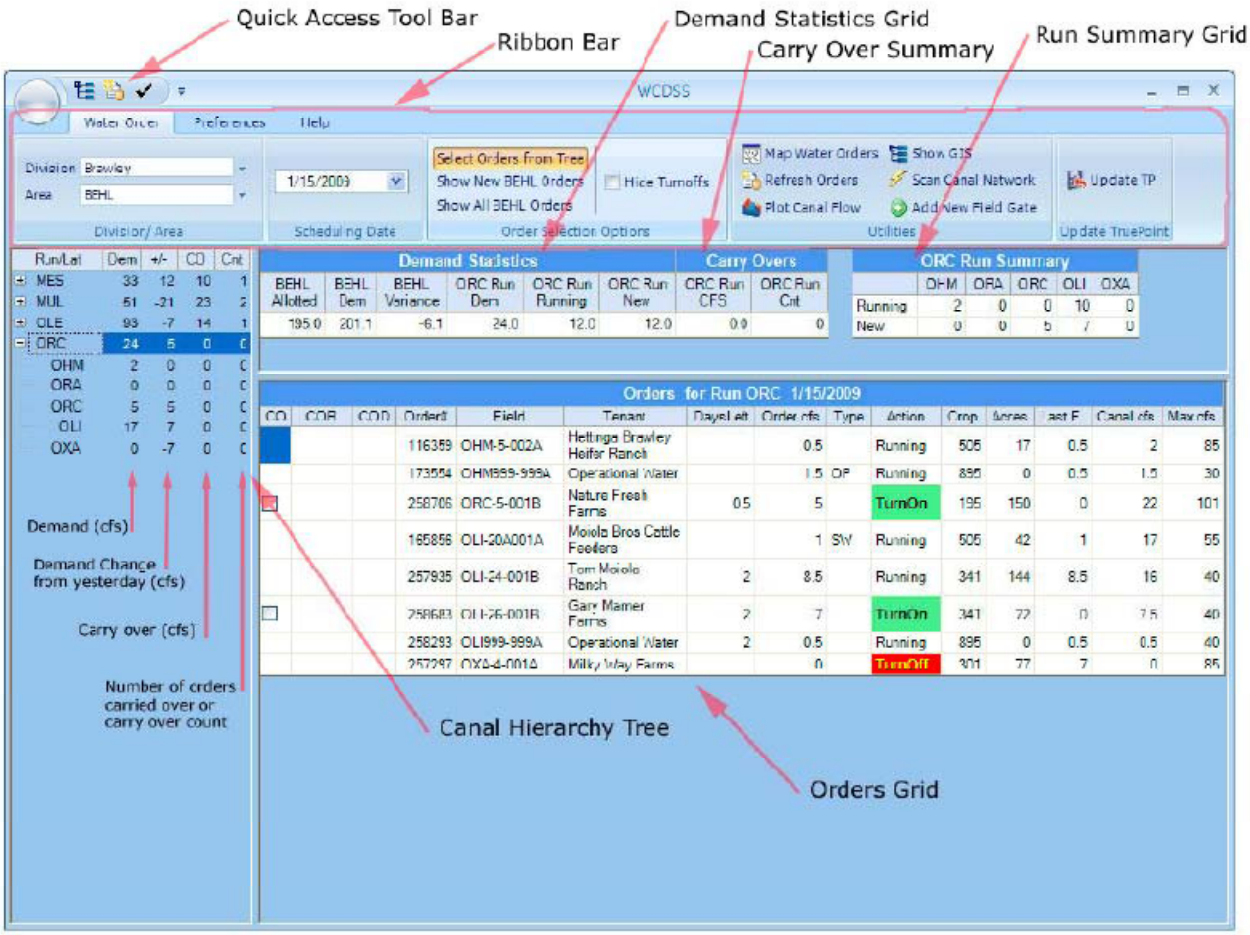
Water Coordinators still enter water orders into TruePoint. This information is stored within TruePoint's internal database (SQL compliant). When a WCDSS session is initiated by a Water Coordinator, the WCDSS software automatically retrieves the current water orders and temporarily saves a copy in a local database running on the WCDSS work station. In addition, through the SQL Server Express application, the current water orders are updated when changes are made in TruePoint, including new water orders. Depending on the number of records retrieved and the connection speed, this replication process can take several minutes.

The main user interface is shown in Figure 20 on the following page. Once the user is in the "Water Order" tab (on the Ribbon Bar), he/she can select the appropriate Division and Area from the drop-down menus. The corresponding zanjero runs are displayed in a hierarchical tree. For the complete canal hierarchy tree, updated information is displayed for the following:

- Allotted – the total flow rate (cfs) allotted to the selected area
- Demand – the total flow rate (cfs) demand for the selected area
- Variance – the difference between the allotted flow rate and the demand flow rate

If the Variance is a negative number – the demand exceeds the allotted amount of water – the basic objective is to carry over enough water orders to bring the variance close to zero. Because the WCDSS automatically calculates an estimated flow at each of the delivery gates with a running order, the system is able to flag water orders that would exceed the canal capacity with the current line-up. These water orders are highlighted in yellow in the Orders Grid.

Figure 20: WCDSS user interface



Source: Irrigation Training and Research Center

To carry over a new water order, the user toggles the check box in the CO column in the Orders Grid next to each water order in the line-up. Once the user has checked for canal capacity violations and determined which new water orders are to be carried over (by bringing the variance close to zero), he/she clicks the Update TP button and this selection is updated in the TruePoint database.

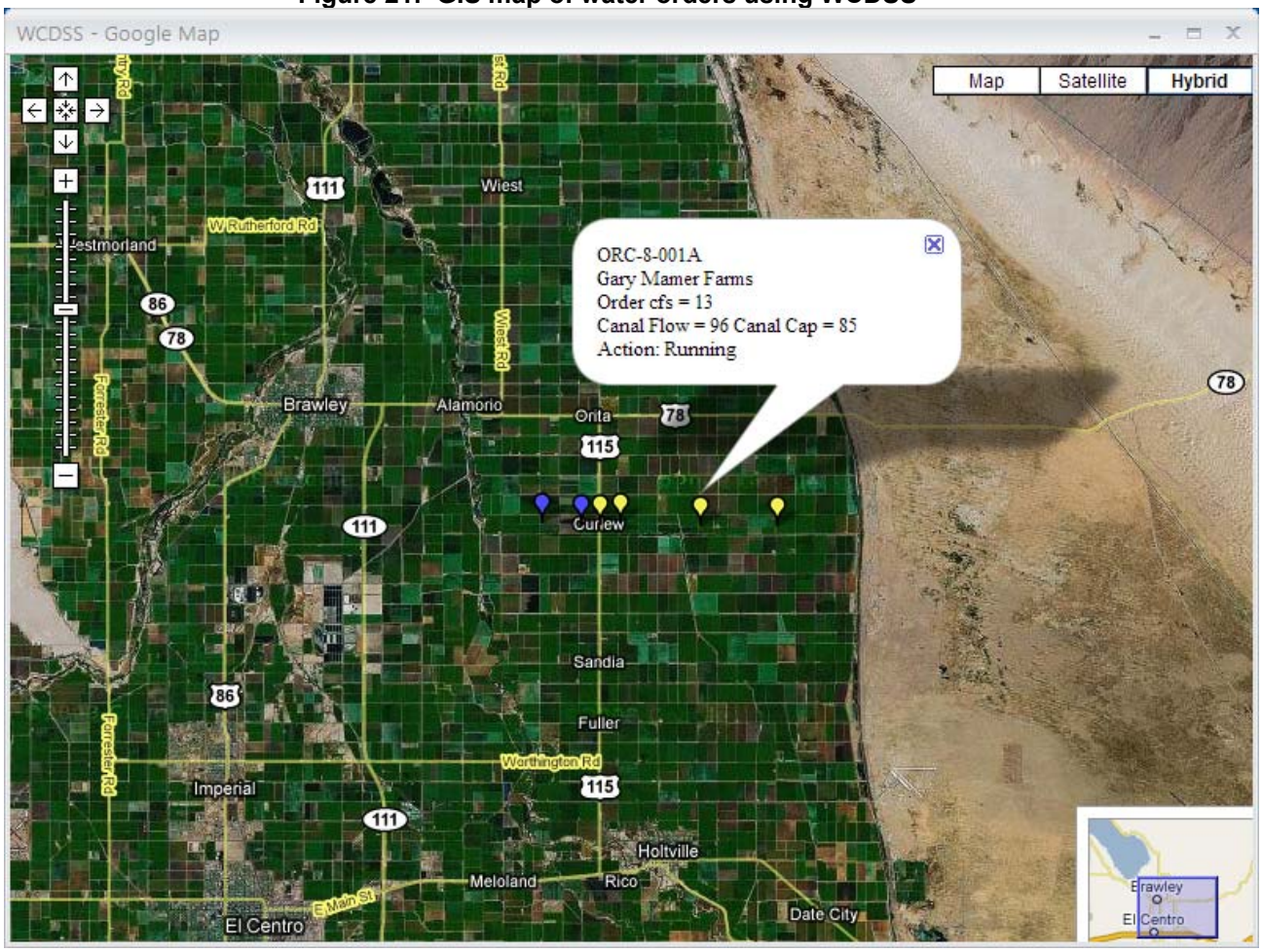
Additional information to aid the user in making this selection of carryovers includes:

- Running orders
- New orders
- Carryovers
- Order count
- Crop type

There is also a built-in simplified GIS component that can be accessed by clicking the Show GIS button. A high-resolution map is displayed in a new window and current information about each water order is displayed along with the locations of all the delivery gates in the canal

network (refer to Figure 21). Information is also shown in the GIS for estimated canal flow rate and the design channel capacity.

Figure 21: GIS map of water orders using WCDSS



Source: Irrigation Training and Research Center

Computerized Data Entry of Water Orders

A separate issue was identified by observing how Water Coordinators manually take down water order information during telephone calls with customers. As is typical of many large irrigation districts, there is a short time-window of a few hours when many people try to call to quickly place a new water order (or cancel an existing one), which means that district staff only have the time necessary to quickly jot down the information and then batch process all the water orders later.

As part of the WCDSS effort, this project conducted an extensive evaluation of tablet PC technology and handwriting recognition software programs in an attempt to create a digital water order form to streamline the office processing of water orders. The effort did not succeed. The best commercially available software tools were not able to provide the required speed and accuracy required for this process. Because the combined hardware and software tools were

not robust enough, the approach was not incorporated into the pilot of the WCDSS. Refer to Appendix 2B for a detailed discussion of this part of the investigation.

Chapter 3: Lateral Decision Support System

Purpose and Background

The basic purpose of developing Irrigation District Routing software was to assist field operations staff with determining the timing and amount of flow changes at various control points in a canal system. In other words, once a schedule of water deliveries is established through a water ordering process, operators still have a major challenge in figuring out what specific control structures need to be adjusted in order to meet the corresponding demands.[3] As operators gain more and more experience as a result of dealing with this on a daily basis, more and more of that experience becomes part of the "art" used to operate the system.

The hydraulics of a large canal network and accounting of flows are so complex that these experienced people can only provide deliveries in an inflexible manner; any more flexibility is too difficult to deal with. The existing infrastructure of many irrigation districts is part of the problem, but this lack of water delivery flexibility created by the limitations of the operators is a serious impediment to how effectively and efficiently growers can utilize the state's resources for agricultural irrigation. Thus, at the practical level of irrigation district operations, improving efficiency is a matter of being able to determine how to route a flow change efficiently through the canal network so that it arrives at the desired point at the correct time.

As explained in the *Project Timeline* section of this report, the routing software program was formulated in tandem with the System Conservation Plan (SCP) at IID. This provided an excellent opportunity for the research team to not only utilize real-world information within existing IT systems, but also to pilot the DSS software in actual field conditions and thoroughly evaluate the results.

Initially, the proposed concept of a routing software program to be applied at IID was quite wide-ranging, with several different stages of planned/possible implementation including:

Level 1 – Enhanced SCADA Data for Field Operations Staff

- Data available
    - Heading, spill and delivery (cfs)
    - Lateral head at each gate
    - Allowable lateral head
- Computed values
    - Lateral pool elevation change and timing to thresholds

Level 2 – SCADA + Revised Operating Rules

- Management of operating ponds for storage
- Guidance on check settings
- Timing of gate opening and closing
- Using indicator checks for spill

[3] The specifics of the water ordering and scheduling processes used by irrigation districts in California vary considerably. Regardless of whether or not a DSS is available for the ordering/scheduling component, the routing component is a separate and distinct function.

Level 3 – DSS component to manage pool storage

- Screen reminder to improve pool management
- Accesses TrueCanal, SCADA, GIS, etc. for additional non-SCADA information
- Pop-up module overlaying basic SCADA screen

Level 4 – DSS component to support early shutoff

- Module 1 – Zanjero enters gate, change in flow, intermediate re-heading (undershot upstream check). Output provides lag-time from heading to re-heading (if used) and re-heading to gate
- Module 2 – Recommendations for heading changes and check changes to best meet orders and reduce spill
- Stand-alone modules that pop up over SCADA and access SCADA, TrueCanal, GIS database, etc.

The DSS for zanjeros was supposed to tell them when and by how much to adjust flows at the headings of laterals in their zone of responsibility so that when a zanjero arrived at the delivery gate to fulfill a scheduled water order, the flow change would have just arrived. In order to accomplish this, the DSS would need to figure out the hydraulics of each the laterals, such as the travel times between delivery gates and operating flow capacities. Knowing that the travel time would depend on the configuration of the check structures (whether it was overpour or undershot or a combination), achieving complete understanding of the lateral's actual hydraulics became an important area of concern.

Implicit in the concept of a DSS for field staff is the requirement that the operator have the ability in real-time to control flows in his/her area of responsibility. Given the size and extent of zanjero runs (their designated zone of responsibility), this basically meant that SCADA and automation were essential components for the LDSS in IID. Specifically, there are three key places where the zanjero needed to have real-time monitoring of conditions and/or the ability to remotely make adjustments to automated structures:

1. At the headgate(s) of the canal
2. At the delivery gate(s)
3. At the spill(s)

Thus, in order to pilot the LDSS and use it operationally, installing an advanced SCADA and automation system was a prerequisite, as described in the following section.

In the spring of 2008, ITRC began doing extensive ride-alongs in IID with zanjeros in order to:

- Learn about the specifics of their routine practices, infrastructure/management constraints, daily hassles, etc.
- Identify suitable areas within IID to pilot the LDSS.

Once the pilot area had been determined – the Orange Lateral – and the appropriate SCADA system installed, including several dozen trials of automated delivery gates, the LDSS was tested in the field for over a year. The results of the field trial led to adjustments in the concept of a workable DSS for field operations as described in the following sections.

SCADA

SCADA is a valuable tool with tremendous potential for enhancing water management in irrigation districts. Many irrigation districts have invested in SCADA as part of the major modernization programs that are underway throughout the state. SCADA systems are widely used for the measurement and control of water. The experience with the LDSS in IID pushed the SCADA frontier even further and demonstrated how smart SCADA technologies can be tailored to provide knowledge-driven tools for operators.

Prior to the development of the LDSS, there was already an existing SCADA system in IID that included several hundred field sites, as well as sophisticated communications and IT networks. Various types of canal and pump automation have been used successfully in IID for many years. As a result, there were core backbone systems in place upon which the SCADA upgrades for the pilot in the Orange Lateral could be built. For example, **Table 23** shows the amount and types of information that is available from the SCADA system at spill sites.

Information from spill sites is important for three distinct reasons:

1. Real-time information is needed by the zanjero to help manage the lateral.
2. Spill volumes, and their trends, must be archived for purposes of:
    a. Verification of spill savings.
    b. Management (division and district) decisions on where problems lie, and making recommendations for reducing spill.
    c. Setting realistic targets for spill.
3. Maintenance, repair, and evaluation of automatic structures by water control and maintenance staff.

The role of SCADA in terms of the required interaction with and support for the LDSS evolved through the development period. As mentioned previously, it was realized that in order for the software to provide meaningful guidance on the adjustments to water control structures, the hydraulics of a given lateral had to be worked on the level that the representative mathematical computations closely matched actual conditions in the field.

To evaluate the possibilities for estimating travel times in actual field conditions, ITRC collected data for several weeks by placing water level sensors in a few active laterals, specifically in canal pools where deliveries were being made. (Note: zanjeros will typically pull check structures completely out of the water unless a delivery is being made in that pool in order to minimize silt build-up and algae growth.) <u>The conclusion drawn from this very important analysis was that it was not possible to predict any relationships regarding travel times, water levels, and deliveries</u>.

The reasoning, however, was fairly straightforward. Zanjeros utilize pool storage to effectively control the movement and speed of water down their canals. In fact, this is a common strategy that almost all operators utilize in canal systems where check structures can be manipulated. For example, by moving a check structure gate down to temporarily hold water back (raising the water level in that particular pool), operators can delay when flows will arrive at a downstream location, which may be needed for a variety of reasons. Add in unauthorized flow changes that can and do also occur at any time, and it was impossible to completely figure out the complex hydraulics of a single lateral even with extensive datasets.

Table 23: Information available in real-time from the PLCs at remote spill/interface sites; reporting interface with WIS

Type of Site	PLC Parameter	Units	Sig. Digits	Real-Time Alarms Generated by PLC	WIS (Archived?)
Pressure Transducer on Weir	Battery Voltage	Volts	0.0	Low battery	
	U/S water level in canal (sensor 1)	Feet	0.00	Sensor fail High water level	Yes
	Flow Rate	CFS	0.00		Yes
	Volume	AF	0.00		Yes
	PLC Time	Date, 00:00:00			Yes
	PLC Program			Intrusion Radio fail	
Automated Gate	Battery Voltage	Volts	0.0	Low battery	
	U/S water level in canal (sensor 1)	Feet	0.00	Sensor fail High water level Low water level	Yes
	U/S water level in canal (sensor 2)	Feet	0.00	Sensor fail High water level Low water level	Yes
	D/S water level in canal (sensor 1)*	Feet	0.00	Sensor fail High water level	Yes
	D/S water level in canal (sensor 2)*	Feet	0.00	Sensor fail High water level	Yes
	Gate position sensor (sensor 1)	Feet	0.00	Sensor fail	Yes
	Gate position sensor (sensor 2)	Feet	0.00	Sensor fail	Yes
	Target water level	Feet	0.00		Yes
	Flow Rate	CFS	0.00		Yes
	Volume	AF	0.00		Yes
	PLC Time	Date, 00:00:00			Yes
	PLC Program			Gate fail Intrusion Radio fail	
Electronic Flow Meter	Battery Voltage	Volts	0.0	Low battery	
	U/S water level in canal (sensor 1)	Feet	0.00	Sensor fail	Yes
	Flow Rate	CFS	0.00		Yes
	Volume	AF	0.00		Yes
	PLC Time	Date, 00:00:00	0.0		Yes
	PLC Program			Flow meter fail Intrusion Radio fail	

* only for spills sites with automated gates that do not always have free flow conditions

Source: Irrigation Training and Research Center

The next step in the process was the idea of using real-time data from the SCADA system, which is GIS-based, about delivery flow rates and times, combined with pool levels in order to predict changes. There were various ideas of looking at the rate of rise in a pool and figuring out when it would overtop. Included in this concept was the idea that each zanjero would have a portable, hardened laptop in his pickup connected to the SCADA system.

An extensive field trial was begun on the Orange Lateral in 2008, in which automated delivery gates were installed along the canal (refer to Figure 22) and connected to an upgraded IID SCADA system. The heading of the canal was automated and an electronic flow meter was installed to remotely monitor canal spill. The zanjeros had portable, hardened laptops installed in their pickups that were connected to the SCADA system.

Figure 22: Automated delivery gate in the Orange Lateral (ITRC sluice gate design)

Source: Irrigation Training and Research Center

It was a major effort to get this LDSS pilot installed and operational. There were numerous technical issues that had to be addressed, including what specific hardware/software was suitable for:

- *Design of the automated delivery gates*
  - As part of this LDSS pilot, IID conducted an extensive field evaluation of about a dozen different gate designs from different manufacturers using various types and complexities of control logic.
  - There were many, many details related to the gate design and operation that had to be designed, specified, programmed, installed, calibrated, tested, evaluated, adjusted, etc. This was done at 26 delivery gates.
- *Communications link between the remote sites and the office*
  - High-speed data radios from different manufacturers were evaluated.
  - Since the field radios had to be incorporated into IID's existing radio network, which actually consists of about four different radio systems (licensed, unlicensed, microwave, etc.), and then put onto a fiber-optics backbone, IID's SCADA technicians had to create a new IP-based Ethernet radio network using a new protocol that was not being used elsewhere in the district (DNP).
- *Communications link between the office and the field laptops*
  - Several options were tested including mobile broadband cards (from Verizon) and a commercial wireless DSL service.

- Once the broadband card method was selected, there were still significant challenges providing them with reliable and secure internet access to the central SCADA server computers housed at the district's headquarters.

- *HMI*
  - IID made the determination, for other reasons in addition to this pilot, to upgrade to a new SCADA host software platform and incrementally switch all remote sites (existing and future) away from FactoryLink.
  - ClearSCADA (by Control Microsystems) was selected as the replacement HMI software, which meant that instead of adding the pilot SCADA sites to an existing, well-tested and developed HMI, the programmers at IID were starting basically from scratch.
- *Laptops*
  - The first decision was whether to use semi-rugged or normal laptops, which involved an analysis of cost vs. performance and durability.
  - Once the semi-rugged option was selected, several brands/models were evaluated (e.g., Panasonic ToughBook, Dell ATG, Itronix and others).

During the field trial, the information that the zanjeros would see via the SCADA system was finessed considerably based on their feedback. There was an initial tendency to want to add more and more information to the screens. However, ITRC quickly found out that zanjeros can get overloaded with information very easily.

Operation of the LDSS

The LDSS tools fall into several categories:

1. Real-time SCADA information. For example, current water levels and flow rates are measured and reported at strategic locations along the laterals. Special HMI screens were developed for the zanjeros' laptops. The zanjeros used these screens to:

    a. View the present status of flows and water levels in their runs

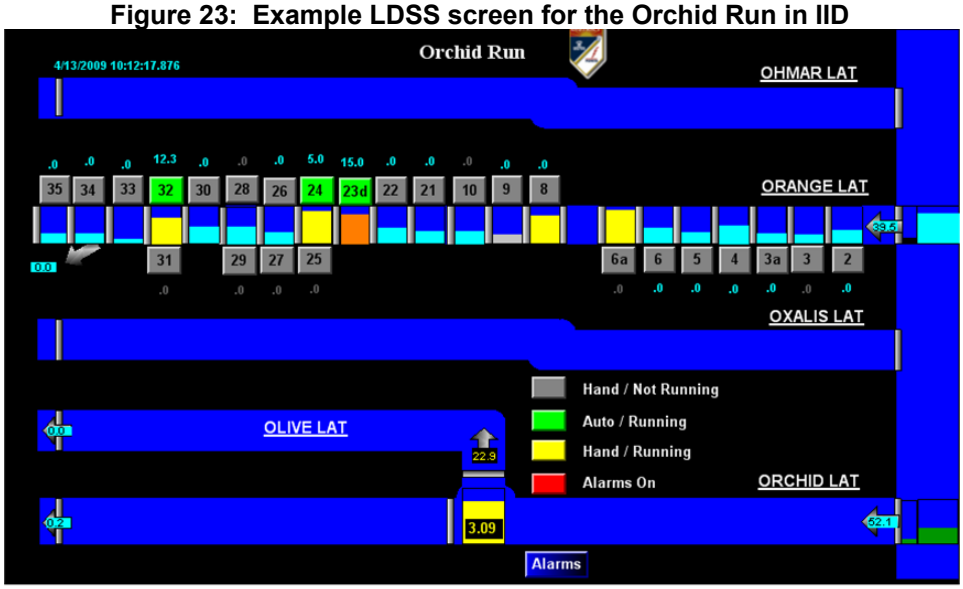
    b. Remotely change target flows at reservoirs and lateral headings

2. Historical SCADA information. The zanjeros have access, through their laptops, to historical trend screens of flows and water levels in their run. These screens are standard screens developed within the HMI that can be "called up" occasionally on demand by the zanjeros. These are also particularly useful for the zanjeros to settle disputes with irrigators that might be due to a low lateral water level, or to identify where and when water may have been inappropriately diverted.

3. Notepad information. Zanjeros are able to write notes on their laptops during their work hours. These notes are accessible as a historical record, but most importantly they are available to the zanjero on the next shift. A note may, for example, state that irrigator "A" on Turnout J15 will probably shut off early – at 3 a.m. rather than at 5 a.m.

An example of a final LDSS screen from ClearSCADA is shown in Figure 23.

Figure 23: Example LDSS screen for the Orchid Run in IID



Source: Irrigation Training and Research Center

The information available on the LDSS SCADA screen in the figure includes:

- Turnout flow rate – There is an alarm if the flow rate varies by more than some assigned amount from the target. The green color indicates a turnout is open.
- The spill flow rate
- The canal head flow rate
- Pool water level, with different colors to indicate if it is low, high, or OK

IID has plans to consider further modifications to the LDSS screens including:

- Color schemes and the fonts used for the captions and legends
- Adding links to the main screen so that zanjeros can easily navigate to other DSS tools, such as the updated run sheets in TruePoint
- Adding more detailed site location screens (e.g., clicking on a flow control site in the main screen takes the user to a new screen that allows a change to target)
- Adding special screens for in-line reservoirs and other facilities
- Rearranging the layout and number of laterals on a single main screen to improve readability on the laptops

In addition to the primary LDSS interface on the laptops running client versions of ClearSCADA, other tools organized and developed as part of this projects are summarized in Table 24. These DSS tools will be a fundamental part of the implementation of the SCP in IID over the next decade.

Table 24: Field operations decisions and associated DSS tools

Decision	Causes for Decision or Explanation	Information Needed	DSS Tools Supplied
Make a flow rate change at the head of the canal	Regularly scheduled delivery gate flow changes (on/off/change) on a lateral without reservoirs or interties	a. Run sheet from division with schedule b. Knowledge of his physical travel time between canals and delivery gates c. Wave travel times at that flow rate and roughness and distance d. Status of various pool levels and storage e. Spill at that moment f. Interaction between on/off locations g. Anticipated behavior by users	a. Improved run sheet from division b. SCADA real-time status of all pool levels c. SCADA real-time status of spill d. Improved control of lateral headgates from WCC, with SCADA
	For a lateral reservoir used by one zanjero. No intertie. How should the potential excess or deficit at the reservoir be considered?	a. AF storage in the reservoir b. Flow rate (CFS) into or out of reservoir – based on rate of rise/fall of the water level	Appears on zanjero lateral SCADA screen, next to reservoir site
	For a new intertie from an adjacent lateral	a. Flow rate from the intertie b. Adequacy of demand or capacity below intertie (communication with downstream zanjero)	Appears on zanjero lateral SCADA screen, next to the intertie site
	For an intertie with a reservoir. Exactly who uses this information and how will be decided later, but the information must be made available.	a. AF storage in the reservoir b. Flow rate (CFS) into or out of reservoir – based on rate of rise/fall of the water level c. Flow rate measured through the intertie d. Adequacy of demand below reservoir (communication with downstream zanjero)	Appears on zanjero lateral SCADA screens for both zanjero runs, next to the reservoir site
Should a flow change at any automated flow control point be pre-scheduled or modified?	The SCADA system will have the capability to store pre-programmed flow schedules, which will be automatically executed. Perhaps for 24 hours in advance.	a. Total orders downstream of that point now b. Total orders downstream of that point at the time of the next scheduled change c. Current flow rate thru flow control device d. Target flow rate thru flow control device e. Next scheduled flow rate f. Time of next scheduled flow rate change	The best display format will focus on zanjero acceptance. It may be too much information to display on the zanjero laptop, on the same screen that shows current flows and water levels. May need a sheet that shows a diagram of the system with current and scheduled flows at the flow control points (not including delivery gates).
	Intermediate pools filling or emptying more than anticipated	a. Real-time spill information b. Knowledge of impending order changes c. Estimate of irrigator behavior in the next few hours	a. SCADA real-time status of all pool levels b. SCADA real-time status of spill
Adjust check gates along a lateral	Desire to temporarily store or release water	Experience that this practice will minimize spill or provide quicker reaction to delivery gates.	SCADA status of spill and pool water levels
	Water level is too high or low in a pool	Observation of water level or complaint	SCADA water levels
	Need to set a check to start or stop a delivery in that pool	Regularly scheduled delivery	Run sheet from TruePoint
Record flows and times to delivery gates	Periodic, standard procedure during deliveries, at beginning, and end	a. Gate opening b. Head difference c. Times any changes were made to the gate position or water level	SCADA historical data of delivery gate information
Resolve disputed delivery record	Farmer complains	Hearsay or observations of actual gate positions and water levels	SCADA historical data of delivery gate information
Utilize storage from a boundary-crossing reservoir		a. AF storage in the reservoir b. Flow rate (CFS) into or out of reservoir based on water level rate of rising/falling	Appears on zanjero lateral SCADA screens, next to reservoir site

Conclusions

This research project successfully developed two prototype irrigation district DSS software systems and put them to use in one the largest irrigation districts in California. This report has summarized the processes leading to their development and highlights important lessons for future efforts.

Lessons Learned

1. Complexity overwhelms operators. Only provide necessary information.
2. The complexity of the dynamic hydraulics cannot be adequately described for real-time use without excellent automatic water level control at all the check structures, automatic flow control at delivery gates (or very hydraulically insensitive deliveries), and SCADA data on actual field conditions that is automatically incorporated into the DSS on a real-time basis. Because IID did not have the first two conditions, the routing DSS could not be developed as originally envisioned.
3. A close examination of existing data management systems can indicate substantial efficiency improvement opportunities without complexity by just simplifying and/or automating some of the procedures (e.g., automatic adding and displaying of information that is now being done manually).
4. If the <u>hardware</u> does not work reliably and accurately, the <u>software</u> has no chance of success. This involves strict attention to detail, use of industrially hardened equipment (e.g., sensors, radios, laptops, etc.), good engineering and design, excellent maintenance, and an appropriate level of capital investment.
5. Real-time SCADA information, available on mobile laptops in the field, can be extremely helpful even without the addition of models and complex calculations.
6. The implementation of new DSS tools for operators and managers at irrigation districts needs to proceed in an incremental manner and the development process must have established opportunities for integrating feedback from users into the development process. This was illustrated by the experience with the WCDSS. The DSS software's functionality closely adhered to the users' original specifications, but by the time it was put into use, the users had already discovered other acceptable methods for achieving the same objectives.
7. There are limitations to what can be achieved with software in terms of improved operational efficiency. This project clearly demonstrated that a proper strategic approach for improving operations in an irrigation district has to balance the right mix of hardware and software. Software is no substitute for things like re-regulation reservoirs, flow measurement devices, canal interceptors, etc.
8. It is extremely difficult, if not impossible, to develop usable DSS software unless the underlying databases, communications protocols, etc. are based on open industry standards.

TASK 3.0: IRRIGATION COMPONENT ENERGY ANALYSIS

Chapter 1: Introduction

Task 3 of the PIER contract with ITRC was to begin the development of an Energy Wise Label Program for Agricultural Irrigation Equipment. One of the important early findings of this work was that it would require a significant amount of time to complete the development of such a label program, primarily due to the multi-year approval process required by the electric utilities. Another finding was that a necessary element of Task 3 would be the characterization of irrigation pump performance in California to establish a pump/pump system energy use efficiency baseline to support the development of the label program. The table below shows the task elements performed for this task.

Table 25: Stages of Task 3

Stage	Subtask	Subtask Elements
1	Index irrigation system components and potentials for energy conservation	
2	Determine current work in progress	
3a	Discuss with utilities and state agencies.	
3b	Develop standards with manufacturers	1. Media filtration tanks 2. New and repaired pump features
3c	Develop a testing laboratory at Cal Poly	
4	Begin testing and assignment of ENERGY STAR label	1. Testing was completed on media tanks 2. Testing was begun on sand wear of pumps 3. White papers for reduced pressure drip/micro systems and for VFDs were completed as prerequisite for ENERGY STAR 4. Characterization of irrigation pump performance characteristics in major irrigated areas of California as a prerequisite for ENERGY STAR

Source: Irrigation Training and Research Center

Chapter 2: Stage 1: Index Irrigation System Components and Potentials for Energy Conservation

Published Studies

There are numerous papers and promotional materials that claim that electricity consumption is reduced by converting to drip/micro-irrigation. However, in most cases drip/micro-irrigation requires a pump, whereas with most surface irrigation no pumps are required. Although each site can be different, in general electric energy consumption for pumping increases when drip/micro is used for irrigation, as is clear from the Task 2.2 report from this project.

A previous study by ITRC for PIER also noted that electricity consumption in California will grow significantly as more farmers convert to drip/micro-irrigation.[4]

Only one research paper was found that specifically addressed the irrigation system view of component energy requirements.[5] The conclusions of Trout and Gartung, based in large part on ITRC-collected data, were:

> Micro-irrigation emitters require only 7 - 20 psi. Cleaning and delivering the water to the emitters on flat fields typically requires an additional 15 psi. A survey of 312 California micro-irrigation systems showed that 60% of the systems exceed these pressures, and 25% exceed by over 10 psi. Pressure could be reduced by an average of 15 psi in 60% of the systems. Pressure was lost at the filter station, in the distribution system, at pressure regulators, in the lateral inlets, and at the emitters. Higher pressure is required to irrigate undulating land. Reducing system pressure by 15 psi in a system could save about $25 per acre per year in electricity costs, and reducing pressure by 15 psi for 60% of the 1.7 million acres of micro-irrigation in California would save 220 Gigawatt-hrs/yr of energy and 90 Megawatts of peak load. (Trout and Gartung 2002)

The recommendations of Trout and Gartung were:

1. Economically evaluate the best pipe sizes for distribution systems.
2. Use pressure regulators or PC emitters only where the benefits in initial costs, water distribution uniformity and system operation are greater than the energy costs.
3. Design filter backflush systems that do not limit system pressures.
4. Use lateral inlet fittings (ball valves, hose screens, spaghetti tubing) that cause little (<0.5 psi) pressure loss.
5. Use booster pumps or variable frequency drives when a pumping plant must operate over a range of pressures or flow rates.

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4 Burt, C.M., D.J. Howes, and G. Wilson. 2003. California Agricultural Water Electrical Energy Requirements, http://www.itrc.org/reports/energyreq/energyreq.pdf

5 Trout, T. and J. Gartung. 2002. Energy Use for Microirrigation. Proceedings of the USCID/EWRI Conference on Energy, Climate, Environment and Water - Issues & opportunities for Irrigation and Drainage, San Luis Obispo, California, USA, July 2002 pp. 465-474

The author of this report notes the following regarding the Trout and Gartung recommendations:

- The benefits of economic pipe sizing are well known in academia. However, a true economic pipe sizing procedure is complex, is not commonly done, and is typically of relatively minor importance.
- New PC emitters now available (since 2002) offer the potential for very low pressure systems, rather than otherwise.
- Stage 3b of this contract addressed filter backflush problems. It is of major importance.
- The importance of using large fittings with low pressure losses is also well known in academia, but often not well understood in the field by designers.
- Variable frequency drives are very strongly recommended in this report, for more reasons than listed by Trout and Gartung.

The energy indexing of irrigation/pumping system components is provided in the sections below. The indexing format is intended to give the reader and utilities a broad, system-wide view of electricity savings potentials in agricultural irrigation systems. Many options are mentioned and discarded. The most promising actions are summarized at the end of this stage.

General

On-site electricity conservation in irrigation can be accomplished through the following general steps:

1. Reduce the volume of water pumped per year
2. Reduce the total pressure required from the pump
3. Reduce other pump power requirements
4. Improve the efficiency of the motor
5. Improve some basic understanding and hydraulics
6. Improve the efficiency of the bowl/impeller assembly of the pump
7. Maintain a high pumping plant efficiency

The primary focus of the agricultural energy conservation programs of the utilities has been to improve the efficiency of the pumping plant. In general, the electric utilities have provided or subsidized pump testing, along with some form of rebate for replacement or repair of pumps.

There are, of course, other irrigation-related aspects of energy conservation. For example, the manufacturing process for nitrogen fertilizer is very energy intensive. Therefore, avoiding leaching of nitrogen fertilizer is an important energy consideration. But this Stage focuses on on-site electricity conservation in the field.

Reduce the Volume of Water Pumped Per Year

This aspect was not the focus of the PIER contract, but is mentioned here because it has been a component of many energy conservation programs.

There is a large appeal to designing energy conservation programs that focus on reducing irrigation applications. There have been various utility-sponsored programs created to accomplish this for at least 25 years. They have focused on one of two aspects:

1. Improve the uniformity of water application in a field. This is logical, because if all plants receive about the same amount of water, there is no need to over-irrigate on the average to provide enough water for the drier spots. There have been two primary utility programs to improve uniformity:

    a. Subsidize the installation of drip irrigation systems. While a properly designed and maintained drip/micro system is inherently capable of (and indeed does accomplish, on the average) applying water with a higher uniformity than other irrigation methods, there are two problems with this type of program:
        i. There are typically no specifications required for drip/micro-irrigation systems that must be met in order to receive a rebate.
        ii. In general, drip/micro-irrigation systems increase kWh per year that is consumed – even accounting for energy needed for conveyance to the site.

    b. Pay for field evaluation of the uniformity of existing irrigation systems. ITRC, with funding from California Dept. of Water Resources, has developed widely used and standardized procedures to evaluation the Distribution Uniformity of irrigation water for most agricultural irrigation systems. Over the past 20 years, there has been a gradual improvement in Distribution Uniformity of drip/micro systems. This is likely due to a heightened awareness of Distribution Uniformity among farmers, manufacturers, and irrigation dealers.

2. Improve irrigation scheduling. The idea is that if farmers have better control of their irrigation systems, plus more pertinent knowledge, they would irrigate fewer hours per year. These programs generally have involved one or more of the following components:

    a. Installation of a flow meter if one does not exist.
    b. Provide irrigation scheduling services, in terms of:
        i. Subsidizing the payment to a commercial irrigation scheduling company.
        ii. Providing information on crop evapotranspiration via the local irrigation district or some other entity.
        iii. Paying for soil moisture sensors, possibly even with remote monitoring.
        iv. Encouraging farmers to use regulated deficit irrigation.

    It is the opinion of the author, based on over thirty years of experience in irrigation scheduling and observation of numerous such programs, that these programs are helpful in a variety of ways but likely result in minimal energy savings. The reasons are:

    a. Quite often good irrigation scheduling will detect under-irrigation and the need for more (not less) water applied.
    b. Soil moisture sensor programs have been in existence for perhaps 50 years, and they are nothing new. Sustained water savings are difficult to document over many years.

c. Many crops are already irrigated with regulated deficits. Assumptions of potential water savings often ignore the existing widespread deficit irrigation of wine grapes, processing tomatoes, cotton, pistachios, and other major crops.

Ultimately, the day-to-day irrigation decisions are typically more complex than one might think when envisioning a water conservation program. Daily irrigation decisions must consider labor, irrigation district inflexibility, spraying of crops, and many other factors. Irrigators and irrigation foremen usually only see risk when someone recommends changes, so changes occur gradually. Over the long haul, there is no doubt that improved irrigation scheduling programs and good flow measurement are necessary tools for achieving high irrigation efficiency without under-irrigation. But broad, positive, quick energy reducing benefits are elusive and are typically assumed rather than documented.

Reduce the Total Pressure Required From the Pump

This item can be divided into several major components:

1. Reduce any friction losses in and around the pump assembly.
2. Reduce friction losses in irrigation system components.
3. Only deliver as much pressure as is needed, through the use of variable frequency drive controls.

Reduction of friction losses in and around the pump assembly

There are several variable friction components for a well pump. These components must be selected when the pump is designed. The first three items are well known to pump companies:

1. Discharge head losses. Discharge head losses are relatively small (typically less than 0.7 ft), and the size of the discharge head is generally determined by the size of the column pipe.
2. Fittings at the discharge of the pipe. The friction characteristics of these fittings are well known.
3. The diameter of the column pipe. All well pump books contain tables for friction loss.

While the three components above are well known, the economics of selecting larger (less pressure loss) components are not well understood or used. Table 26 illustrates the importance of economic selection that includes knowledge of hours per year pumped, interest rate (assumed to be 6%), years life of investment (assumed 10 years), and power cost (assumed $.15/kWh).

Table 26: Economic break-even flow rates (GPM) with various column diameters.

Column Diameter Choice	Hours/year					
	1000	1500	**2000**	2500	3000	4000
8" vs. 10"	1025	887	800	750	695	631
10" vs. 12"	1870	1620	1440	1335	1275	1130

Source: Irrigation Training and Research Center

Table 26 shows that with **2000** hours/year of pumping, at a flow rate of 800 GPM there is no economic benefit to using either an 8″ or 10″ column diameter. However, any flow between 800 and 1400 GPM should use a 10″ column diameter. At 1441 GPM, a 12″ diameter is more economical than a 10″ diameter column pipe.

There is no simple rule regarding the appropriate column pipe diameter, based on the bowl diameter. A typical bowl assembly is often offered with at least 3 standard options for column pipe connections. Furthermore, a 12" bowl may be designed for 800 GPM or for 1200 GPM.

The next two items are not well understood or recognized.

4. Entrance losses in well pumps, primarily due to entrance screens. This is rarely considered, but it should be often. Standard mild steel entrance screens can become almost completely fouled, which not only increases the pressure requirement of the pump, but also eliminates proper hydraulic entrance conditions into the first impellers – lowering pump efficiency.

Figure 24: A proper stainless steel entrance screen for a well pump

Source: Irrigation Training and Research Center

Figure 25: Example of a corroded entrance screen

Source: Irrigation Training and Research Center

5. Coating of the inside of the column pipe to reduce friction. A variety of coatings exist, and smooth pipe materials such as stainless steel are available. One of the biggest problems is avoiding pinhole cracks that will accelerate local corrosion and cause flaking of the coating.

If the drawdown (Initial water level in well – Final pumping water level in well) can be minimized, the pump does not need to provide as much pressure. The three most important human-impacted variables that influence the drawdown are:

1. The quality and cleanliness of the well screen. Screens cost money up front. Holes poked in well casing are cheap, but a good screen has numerous initial and long-term advantages that save power in the long run. These advantages include:
   - They allow for good development of a well (see below).
   - They have a large percentage of open area – easily 3-4 times as much as inexpensive slots or holes in casing. This means there is less head loss between the aquifer and the well (meaning less drawdown), and the lower velocities also help minimize corrosion and chemical blockage.
   - Good materials do not corrode. Corrosion blocks the entry of water into the well, increasing the TDH and decreasing the yield (flow rate).

2. Proper development of the well after it is initially drilled. Development is the process of cleaning out the soil immediately around the well screen to allow for free flow of water into the well (and thereby decreasing drawdown). Proper drawdown involves a lot more than just "overpumping" (the common practice), which just improves the opening of already-clean zones. Well development procedures are well described in the book "Groundwater and Wells" by the Johnson Division of Driscoll.

3. Cleaning of a fouled well screen. The fouling can be caused by any number of factors such as calcium carbonate, iron bacteria, or rust.

The economic and energy impacts of the factors above are summarized in Table 27.

Table 27: Opportunities for total pressure reduction around a well pump

Action	Likely difference in Total Dynamic Head (Pressure) - feet	Is this already common practice?	Opportunity for success in adoption and energy savings if targeted by utilities (1 = very poor; 10 = excellent)	Comments
Larger discharge head	0.30	N	1	
Larger pipe fittings	0.5 – 10	Y	4	Already understood; Computation tool might help
Large column diameter	5 – 30	N	8	Need simple calculation tool
Good pump entrance screen	0 - 15	N	10	Need awareness and simple rebate. Minimal expense; high benefit.
Column pipe coating (powder coating)	1 – 9	N	5	Coating must be high quality, or it will crack and corrode
Good well screen	2 – 40	N	4	Difficult to predict benefits in advance
Proper well development	1 – 10	N	8	Relatively simple to achieve
Screen cleaning	2 – 40	Variable	4	Need better documentation. Very site specific and must be targeted. Falls under maintenance.

Source: Irrigation Training and Research Center

Reduce pressure requirements in the irrigation system (downstream of the pump)

There are two initial points to be made regarding this possibility:

1. It should be obvious that reducing pressure requirements of the irrigation system itself can potentially conserve energy. However, reducing the pressure requirement of the irrigation system, without changing the pump to match the new pressure requirement, may result in no electricity savings.
2. The only utility rebate program that ITRC is aware of that has directly rewarded farmers for pressure reduction is related to "low pressure nozzles". These are discussed in the Sprinkler Component section.

Surface Irrigation Components
Surface irrigation (furrows, border strips, and basins) typically have very little pumping requirement, although there are exceptions when long conveyance pipelines are used. The major savings related to surface irrigation would in concept occur via improving irrigation efficiency – thereby reducing the electricity needed to pump the water to field (e.g., California Aqueduct, Delta-Mendota Canal, well pumps).

However, water contractors that receive water from the California Aqueduct and the Delta Mendota Canal have limited water allocations. Therefore, if water applications are reduced on one field, they will be increased on other fields – the volume is limited and therefore will not be reduced overall if efficiency is improved on one field.

For well pumps, the savings is more direct. If 50% less water is pumped, there is a 50% reduction in electricity (not including additional electricity requirements to improve the irrigation efficiency).

The ways to improve irrigation efficiency with surface irrigation are well documented by Burt[6] and many others. Summarized, the two modifications that are most useful in California are:

1. Reduce the length of the basins, border strips, or furrows.
2. Install a tailwater return system (which, by its nature, requires a pump).

The difficulty with surface irrigation improvements in California is that it is challenging to make good estimates of the water (and therefore the energy) that will be conserved. Quite often, there are no records of actual water deliveries to individual fields. Also, field evaluations only give limited information with inexperienced evaluators, because the nature of water advance and infiltration varies greatly throughout the season. Furthermore, irrigation efficiency estimates must include excellent computations of the efficiency of individual irrigation events.

Sprinkler Components
Within the sprinkler industry, there have been two primary items that have been promoted for reduced pressure requirements:

1. Use of low pressure sprinklers on center pivots and linear moves. This is now standard practice in the industry. The older, high pressure (50 – 60 psi) sprinklers have almost been completely replaced by relatively lower pressure sprinklers (10 – 20 psi). The newer low pressure sprinklers have additional benefits such as better distribution uniformity and less wind drift. The major manufacturers of the low pressure sprinklers are Nelson Irrigation (www.**nelsonirrigation**.com) and Senninger Irrigation (www.**senninger**.com), both of which are US companies.

6 Burt, C.M. 1995. The Surface Irrigation Manual. Waterman Industries

2. Use of "low pressure nozzles" on hand move sprinklers and side roll (wheel line) sprinklers. These have been included in various electric utility rebate programs, but they have some significant disadvantages in terms of larger droplets which tend to crust the soil surface, and a lower pressure uniformity among sprinklers throughout the sprinkler system. When one considers the disadvantages of converting a higher pressure nozzle to a low pressure nozzle, especially without also changing the pump at the same time, it is questionable whether there is an overall energy savings.

Other standard options such as using larger pipelines are applicable to all methods of irrigation, including sprinkler irrigation.

There are a variety of measures that can be used to improve distribution uniformity of the water application. Although they have the holistic benefit of improving crop yield, they may or may not have an impact on electrical consumption. The most simple and cost effective such component is the use of pre-set pressure regulators under every sprinkler in hand move and side roll sprinkler systems.

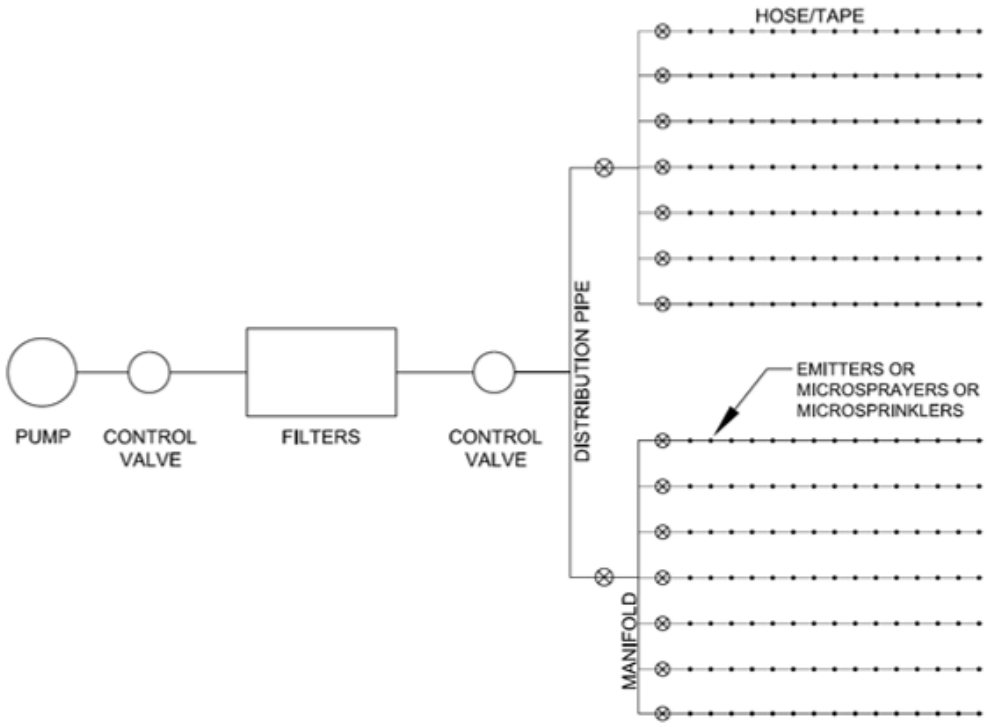
Drip/Micro-Irrigation Components

The terms "drip irrigation", "microirrigation", and "trickle irrigation" can be synonymous although they can refer to the design of the final emission device. These systems are often referred to as "low pressure systems", although a typical California pump discharge pressure is about 40 – 45 psi on flat ground (even though the emitter may need 6-12 psi pressure). A detailed explanation of options and designs can be found in (Burt, C.M. and S. W. Styles. 2011. Drip and Micro-Irrigation and Management. ITRC. Cal Poly. San Luis Obispo).

The study by Trout and Gartung, written 10 years ago, highlighted several important topics. Certainly, if typical emitters only need 6-12 psi of pressure, one must question why typical drip system pump discharge pressures average about 45 psi on flat ground. Further discussion is provided here, with specific recommendations.

The figure below is a conceptual sketch of a drip/micro-irrigation system with key components.

Figure 26: Drip/micro-irrigation system schematic.



Source: Irrigation Training and Research Center

To minimize pressure requirements at the pump discharge, one must consider the pressure requirements for water to flow through each of these components.

1. Control valves near the filter. All control valves have friction loss, but there are significant differences between various sizes and models. There is very little new knowledge here, and some excellent control valves exist for this location.

2. Filters. This is one component that has significant room for improvement. Therefore, ITRC conducted a major study of media filter performance as part of this contract. The large pressure loss that is built into drip and micro-irrigation systems for filters is not needed if the correct filters are used. The major factors are:
   a. Some filters, such as the various internal-wand-cleaning screen filters, and various disc filters, require 35 psi minimum to properly backflush.
   b. Media filters (most common type) are often thought to require 35 psi to backflush. The ITRC filter study (Appendix 3A) shows this is not a universal requirement.

   Because the filter backflush pressure requirement is so large, there is typically no reason for designers to select low pressure loss valves and fittings within the irrigation system. In other words, items #3-6 below are not very important unless the proper filter is selected.

3. Control/pressure regulation valves within the distribution system, and at the heads of tapes and hoses. Depending upon the model and design, there can be significant pressure savings if valves are carefully selected. There are two types of pressure regulation valves:

a. Pilot-operated valves. These are usually 2" or larger in diameter, and are used at the heads of manifolds, especially with tape systems. There is a major, little known hydraulic fact about many of these valves: if the downstream pressure is 8 psi (typical for drip tape), there may be a 10 psi loss across the valve for a flow of 100 GPM. But if the downstream pressure is 20 psi, there may only be a 2 psi loss across the valve for a flow of 100 GPM. The manufacturers publish the 2 psi value, not the 8 psi. Irrigation designers do not know which valves have these characteristics, or that they even have them. Designers do know that they need a substantial "safety factor" of extra psi for the pump to take care of things like this.
b. Pre-set pressure regulators. These pressure regulators are typically used at the heads of hoses in hilly terrain. They can have large (3-6 psi) friction losses across them when wide open.

4. Fittings on hose risers can be small and have appreciable friction loss. There is no standard in the industry for these fittings, and the friction loss of the various assemblies that are used is not well known.

5. Drip hose/tape hydraulics. These are fairly well understood. All the major manufacturers have good hydraulics programs that they provide to irrigation designers. ITRC has a similar program for education that is used my many designers. They all perform the same functions – the uniformity of water discharge, friction, pressure requirements, etc. are automatically computed if one inputs the slope, hose diameter, emitter specifications, etc.

6. Emitters and microsprayers and microsprinklers. These are the final emission devices. Many of the designs have not changed for many years. For discussion, there are two basic types of emission devices: Those with fixed holes, and those with some type of pressure compensating (PC) ability that requires some type of flexible diaphragm inside the emission device. There are some very interesting possibilities at this level, such as:
   a. Standard, fixed hole/path emitters must have a minimum pressure of 6-12 psi just to maintain good uniformity of discharge along the hoses and between hoses. When there is elevation variation, a higher optimum average pressure is needed to maintain good uniformity.
   b. Pressure compensating (PC) devices have the interesting possibilities:
      i. There are very few PC emitters (discharging somewhere between 0.5 and 1.0 Gallons/hour) that can operate very well at pressures as low as 4 or 5 psi. This means that at a wide range of pressures, say between 4 and 35 psi, the flow rate is almost identical. Especially for hilly terrain, this feature can offer substantial (at least 10 psi) pressure reduction benefits.
      ii. Microsprinklers are emission devices which have a stream of water (e.g., 15 Gallons/hr) that is rotated to provide a large amount of ground coverage. The most popular PC microsprinklers do not work well until the pressure at the microsprinkler is about 25 psi. ITRC was unable to locate any commercially available low pressure PC microsprinklers.
      iii. Microsprayers are emission devices with relatively large flows (e.g., 15 Gallons/hr) that discharge from a nozzle, hit a fixed plate, and then spray out with multiple jet patterns. Bowsmith Industries (Exeter, CA) recently developed a PC microsprayer that begins to function well at relatively low pressures (8 psi). As with PC emitters, this is important for hilly terrain.

Rebate Programs for Drip/Micro-Irrigation. Drip/micro-irrigation rebate programs offer substantial holistic potential benefits in terms of improved fertilizer efficiency and increased yield. These two items can produce more crop per drop of fertilizer and water consumed.

Such rebate programs might require numerous specific features such as the correct flow rate, appropriate air vents, good fertilizer injectors, certain thicknesses of tape, and so on. But perhaps more importantly, the following key performance results should be specified:

1. The new system Distribution Uniformity, as measured with the Cal Poly ITRC drip/micro-irrigation evaluation procedures, must be greater than 0.92
2. The pump discharge pressure shall be no greater than the following:
   a. For tape systems: 23 psi, plus the difference in elevation between the highest point in the field and the pump discharge.
   b. For emitter and micro-spray systems: 27 psi, plus the difference in elevation between the highest point in the field and pump discharge.

The values are obtained using readily attainable pressure losses, as shown in **Table 28.**

Table 28: Readily attainable pressure losses

Item	Pressure required for different systems	
	Tape	Tree/vine
Emitter	6	10
Hose/tape	3	3
Fittings, valve losses	2.5	2.5
PVC main and manifold	3.5	3.5
Filter	5	5
Control valves, check	3	3
TOTAL	**23**	**27**

Source: Irrigation Training and Research Center

Perhaps there could be a $200/acre rebate for new systems meeting the pressure and uniformity criteria, plus an additional $40/acre rebate for every psi reduction below the *total* listed above.

Pressure Reduction with VFDs. Variable frequency drive (VFD) controllers for irrigation pump motors may have the greatest potential for immediate power savings. There are numerous reasons to promote VFDs on both well pumps and booster pumps. These include:

1. Designers must always over-design pumps. Farmers do not complain if they have too much pressure; but they definitely complain if they do not have enough. The uncertainties with pump design are:
   a. As mentioned above in the discussion regarding drip/micro-irrigation, designers always include a "safety factor" of at least 5 psi in a design – whether needed or not.
   b. Published pump curves often do not exactly match what does into a field.
   c. The pressures from irrigation district pipeline turnouts vary over time, and may not even be known by the designer.

d. Well water levels vary from year-to-year, and from Spring to Fall. These variations can easily be 50 feet.

2. Irrigation systems do not require a constant pressure. In general, irrigation systems have multiple blocks that are sequences. These blocks have varying elevations and sizes, each with unique pressure requirements.

In summary, given the two items above, VFDs allow designers to over-design the pump to meet uncertainties and occasional extreme conditions, without having continuous power wastage due to an over-designed pump.

There are three other substantial benefits derived from the use of VFDs, although they do not in themselves reduce electricity consumption (kWh). These benefits are:

3. Water hammer and subsequent damage to the pump and irrigation system are reduced because of the slow start and slow stop capabilities of VFD-equipped pumps.

4. Farmers are much more likely to adopt time-of-use pumping practices with well pumps. This is because the slow starting of well pumps, as opposed to 100% speed starting (with subsequent very high flow rates), can have a drastic impact on the life of wells. Many farmers will not start or stop well pumps during the irrigation season because they are afraid the starts and stops will damage their wells.

5. The slow start minimizes large but temporary current loads on the electric utility grid.

Given that VFD controllers can provide substantial energy-related benefits with agricultural irrigation pumps, any rebate program for VFDs should contain minimum requirements for the purchase of VFD controllers, covering the following features:

1. Efficiency. Inefficient VFDs create excess heat which requires significant air conditioning power to dissipate
2. Temperature rating
3. Power quality
4. Form of the simulated sine wave
5. Audible noise
6. Length of power cords that can be used. Some low quality VFD units can only have a cable of about 20 feet long between them and the motor
7. Means of cooling the VFD
8. Allowable voltage variation between legs
9. Allowable average voltage variation

Reduce Other Pump Power Requirements

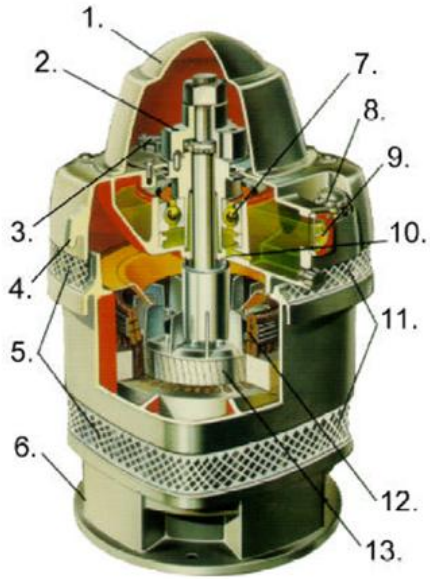
The primary "other" components in pumps are the bearings. There are two types of bearings that interest most pump people:

1. "Thrust bearings", which are located in the motor. These are designed to allow the shaft and rotor to rotate while experiencing downthrust from the weight of the shaft and the dynamic thrust of the impellers. Thrust bearing power requirements can be computed, but are often assumed to equal 0.5% of the brake horsepower requirement of the impeller/shaft. Other than having good maintenance (proper lubrication) and balancing, thrust bearings are not a major item to consider in reducing electric energy requirements for pumps.

2. Mechanical friction in line shafts. This can be appreciable. The values typically range from about 1.0 to 2.0 brake horsepower per 100 feet of shaft, when new. If there is poor lubrication or wear on the line shaft bearings, the horsepower requirement increases.

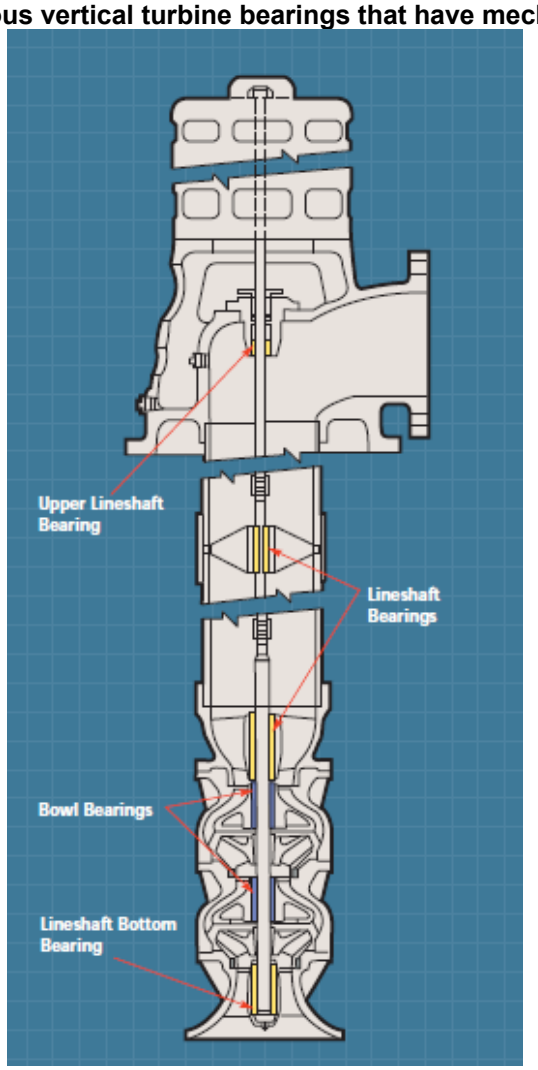
Figure 27: Vertical turbine Holloshaft® motor cutaway.

1. **Lightweight Top Cover**
2. **Coupling** readily accessible
3. **Lockbar** holds shaft during adjustments
4. **Lifting Lugs** positioned for stability
5. **Protected Air Openings** exceed NEMA WPI requirements
6. **Precision Machined Mounting Base**, ample clearance for mounting bolt installation
7. **Rugged Bearing** withstands heavy load thrusts
8. **Large Plug** simplifies oil fills
9. **Sight Gauge Window** for quick oil level reading
10. **Metered Oil Flow** minimizes churning
11. **Dual Air Flow** system for uniform cooling of motor top and bottom
12. **Windings** Protected by new, synthetic materials
13. **Solid Die Cast Rotor** with integral fan blades



Source: US Motors

Figure 28: Various vertical turbine bearings that have mechanical friction.



Source: Thordon

In general, deep well irrigation pumps have historically had redwood or bronze oil lubricated bearings enclosed in an oil tube that surrounds the bearings and lineshaft. Bronze bearings are almost the universal choice by pump repair companies in California and manufacturers.

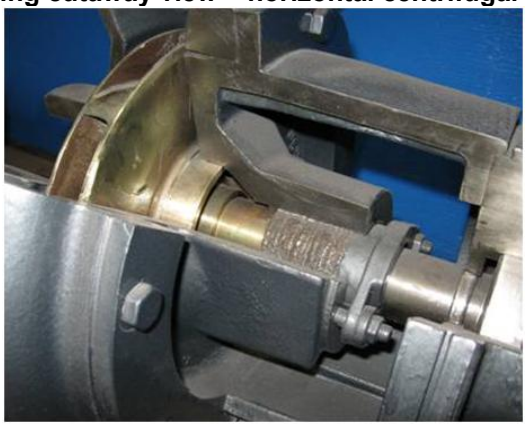
Nevertheless, ITRC thinks that it would be worthwhile to examine the merits of new material for oil lubricated bearings. Taking a typical 300′ pump length in California, the present bronze bearings need about 3-6 horsepower to overcome mechanical friction when new. As they get older, they wear not only themselves but also the lineshaft. New materials should be able to reduce the friction in half, as well as provide longer wear. This appears to be a relatively simple way to save power. Vesconite, which is described below for water-lubricated bearings, is not suitable for oil lubricated bearings because the temperature must be kept below 60 deg. C. There is not enough oil passing through the bearings to maintain this temperature – especially at startup of a deep well turbine.

Although rubber water lubricated ("product" lubricated) bearings are available for vertical lineshaft turbines, they have historically suffered damage if the pumping water level is quite

deep; the shaft spins on dry rubber bearings for a long time before water arrives to lubricate them. Similarly, for large flow rate vertical pumps used by irrigation districts to lift water from canals or rivers, there is often a problem with silt. Therefore, even if the bearings will not be dry for an appreciable time, the silt in the lubricating water can wear out the bearings, and increase the line shaft friction over time.

Horizontal irrigation centrifugal pumps typically have water-lubricated "packing," as seen in the figure below. A recommended packing material is graphite impregnated, such as John Crane® 1340 graphite acrylic. The packing is typically tightened to allow about 2-3 drips/second, which minimizes mechanical friction.

Figure 29: Packing cutaway view – horizontal centrifugal irrigation pump.



A number of synthetic bearing materials have been introduced to reduce mechanical friction and to overcome problems of lubrication wear and friction with product (i.e., water) lubricated lineshafts. They are not used on oil lubricated lineshafts because they are not sufficiently cooled, and because some of the materials are incompatible with oil. Several of the major materials for water lubricated bearings are listed below:

- Graphalloy®. This is a self-lubricating graphite/metal alloy used for bearings. It is claimed to be non-galling, corrosion resistant, and dimensionally stable, and is sold for both vertical and horizontal pumps.
- Thordon SXL®. These bearings also are sold on the basis of having low friction, impact tolerance, and self-lubricating qualities.
- Vesconite®. Vesconite is a specialized thermoplastic made from internally lubricated polymers that has been available since the 1960's. It has no water swell, does not delaminate, remains hard in water, has a low friction, and gives many times the life of phosphor bronze, and easily machined. Because of these characteristics, it has become popular with some vertical pump manufacturers, and in many pump repair shops in California.
- Duramax OEM Cutless® industrial bearings.

Improve the Efficiency of the Motor

The electric utilities have had rebate programs for many years for using high efficiency motors. However, the benefit is likely not as great now as several years ago. The motor efficiency standards for "standard" motors have improved to the point that the efficiency of some "high efficiency" or "premium" motors is the no better than that of "standard" motors.

Perhaps one area for improvement would be to use slightly better insulation classes for motor windings. The choice of insulation depends on the maximum expected windings temperature. If the expected temperature is close to one insulation class it is better to select the next higher insulation class for the motor winding.

A typical inverter duty hollow shaft motor for an irrigation well pump will have an insulation class of "F." As seen in the table below, an insulation class of "H" would reduce the importance of keeping the motor cool.

Table 29: Insulation classification MG1-1.66

Insulation Class	Temperature Rating
A	105° C
B	130° C
F	155° C
H	180° C

Source: Irrigation Training and Research Center

Improve Basic Understanding and Hydraulics

The following two items are rather basic, but need attention.

Obtain a pump curve. This may seem only logical, but in many areas of California it is unusual that the farmer is supplied with a pump performance curve that shows the relationship between flow, pressure, and efficiency – plus the design operating point. Any rebate program should insist that farmer receive a pump curve.

Improve the entrance conditions on booster and short-coupled vertical pumps (vertical pumps in sumps rather than in wells). ANSI/HI 9.8-1998, Pump Intake Design (from the Hydraulic Institute Standards) provides great detail about proper inlet design for pumps. A distorted velocity profile entering the suction side of pumps can contribute to excessive noise, cavitation, and uneven loading of internal bearings. The exact effect of poor entrance conditions on pump efficiency is not known, but anecdotal experience indicates that the impact can be rather severe – such as 5-10 percent drop in efficiency.

For short-coupled vertical pumps, the ANSI standards are fairly straight-forward to follow. Pump dealers, however, rarely attempt to follow more than minimum guidelines from the ANSI standards with agricultural irrigation pumps. ANSI standards are well known to consulting engineers working for irrigation districts.

The best opportunity for significant and simple modification of inlet conditions comes with horizontal booster pumps. The figures below show "typical" installations for booster pumps, all of which have elbows close to the inlet of the pump.

Figure 30: Typical installations for booster pumps with elbows close to the inlet of the pump

Source: Irrigation Training and Research Center

Most pump dealers understand the need for long, straight (6 – 10 diameters) sections of pipe upstream of flow meters. But that knowledge is rarely applied to the installation of the inlet piping for booster pumps. In part, this is likely because pump installers do not know the specific, quantitative effect of inlet conditions on efficiency. In part, it is likely due to the need to have short pipes just so the installation fits within allowable boundaries.

Within the past few years, there has been increased promotion by flow meter companies of new "flow conditioning" equipment that can be placed in front of propeller flow meters. This flow conditioning equipment accomplishes two things in a short pipe section:

1. It minimizes or eliminates swirling of the water.
2. It straightens out the velocity profile so that it is concentric about the center of the pipe.

Elbow flow conditioners can be installed upstream from critical equipment requiring a swirl-free, repeatable, and symmetric velocity profile.

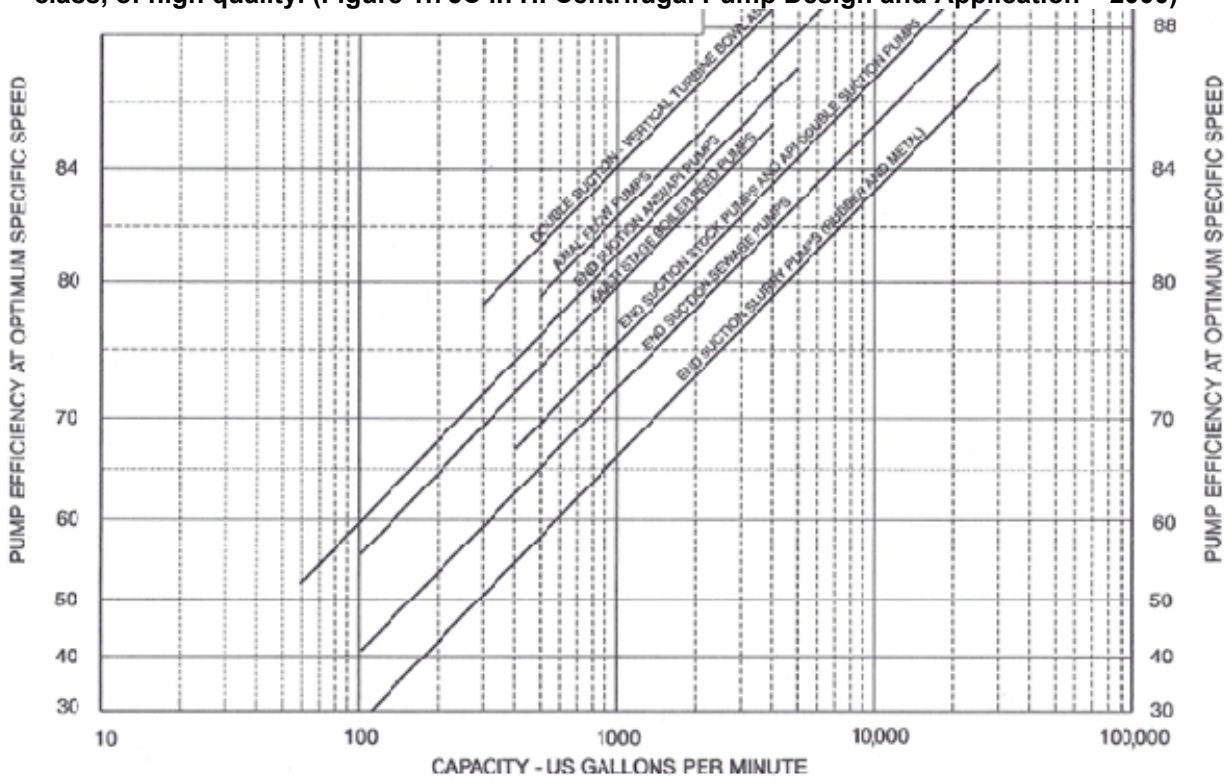
The same concepts could be applied to a simple rebate program. Companies such as VORTAB offer special inserts and pipe sections that provide excellent entrance conditions to pumps with limited space.

Improve the Bowl and Impeller Efficiencies

Attainable bowl/impeller efficiencies

The figure below illustrates generally attainable efficiency levels of centrifugal pumps at the best efficiency point, with the maximum diameter impeller when pumping clear water. Well pumps fall under the category of "vertical turbine bowl" (the uppermost curve); most booster pumps fall under the "end suction ANSI" (the third from the top curve) category.

Figure 31: Optimum generally attainable efficiency for bowl/impeller assemblies of industrial class, of high quality. (Figure 1.75C in HI Centrifugal Pump Design and Application – 2000)

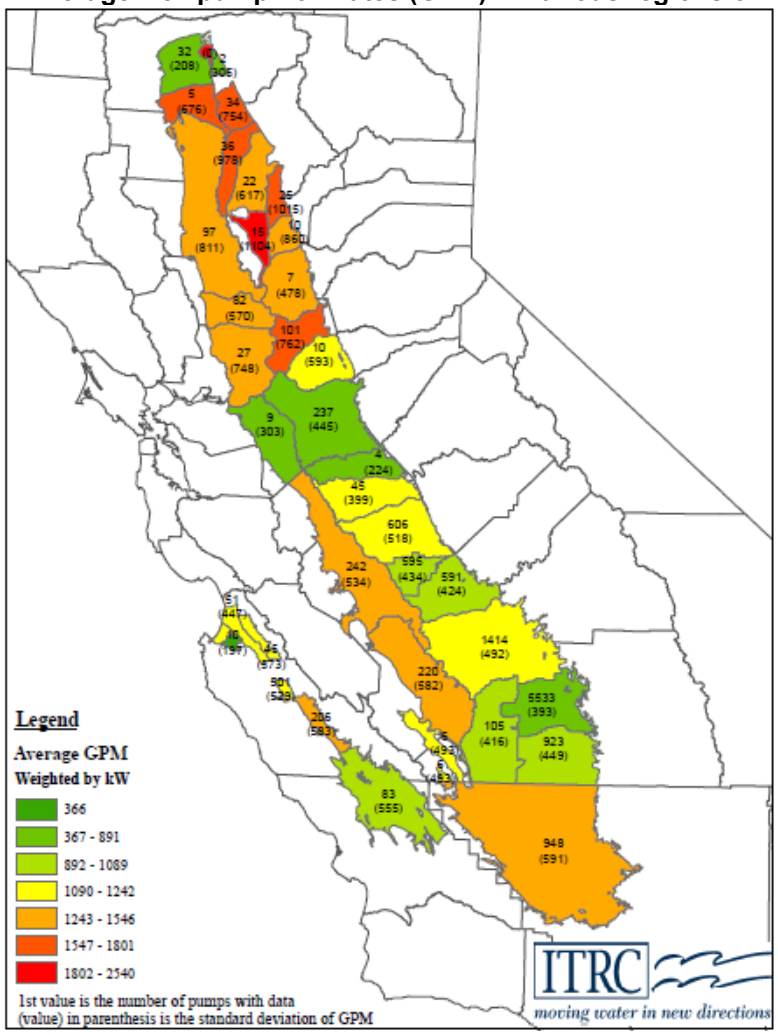


Source: Irrigation Training and Research Center

Most well pumps in California range from about 500 GPM to 2000 GPM, as seen in **Figure 32**. Therefore, maximum potential efficiencies of bowl/impeller assemblies range from about 82% to 86% on well pumps. Attainable improvements in efficiency must therefore use such numbers as the "base efficiency values." For the discussions below of various options, a base efficiency value of 84% will be assumed.

Improvements of efficiency due to specific actions are not additive. Although the compounding mathematical effect of independent actions can be computed, there may be physical interactions when multiple actions are implemented to improve efficiency. The discussions below consider the actions individually.

Figure 32: Average well pump flow rates (GPM) in various regions of California



Source: Irrigation Training and Research Center

Coat the impeller/volute/bowl for smoothness

The Hydraulic Institute provided an estimate of the benefit of improved smoothness in the figure below in 2000, but this figure has been removed from the most recent Hydraulic Institute Pump Standards.

The specific speed of an impeller is defined as:

$$\text{Specific Speed} = \frac{(n \times GPM^{0.5})}{Feet^{0.75}}$$

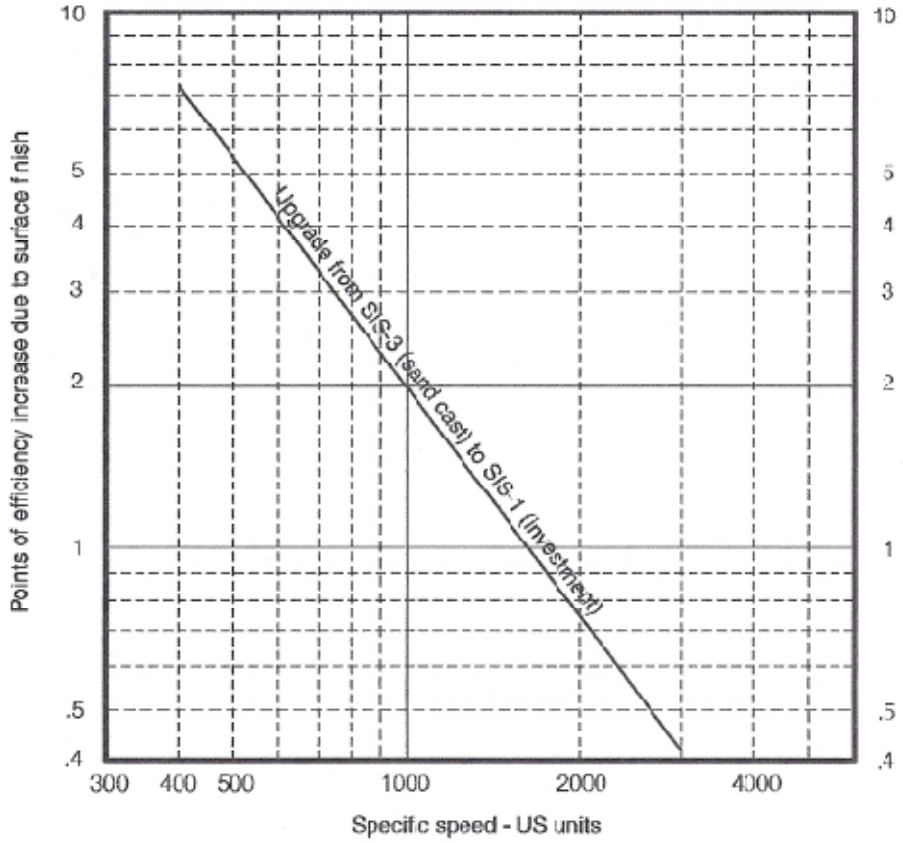
Where

n = RPM of the pump

Feet = the head per impeller stage

A typical specific speed for a typical California agricultural well pump is 3000.

Figure 33: Likely increase in bowl/impeller efficiency due to improved smoothness. (Figure 1.77B in HI Centrifugal Pump Design and Application – 2000)



Source: Irrigation Training and Research Center

Figure 33 shows less than 0.5 percent efficiency benefit from smoothing of impellers and bowls for typical agricultural well pumps. But interviews with manufacturers and smooth compound vendors indicate that improving smoothness will give several percentage points of efficiency improvement if impellers and/or bowls are smoothed.

The general rules for smoothing of impellers appear to be:

1. Impellers smaller than 16″ or 18″ in diameter are typically not smoothed by applying an epoxy-type coating. The impeller waterways are too narrow, which makes it too difficult to uniformly apply epoxy coatings, and the small openings can also plug. This means that epoxy coating is suitable for typical on-farm pumps (both vertical and horizontal). However, epoxy coatings should be reserved for re-conditioning impellers, rather than for new impellers.

2. There is a large difference in new impeller qualities among various manufacturers. High quality manufacturers, on a standard basis, employ good casting designs and have swirl machines on site to polish impellers. They place the newly cast impellers in a bath of abrasive material and spin the impellers to polish the impeller passages. They also hand polish impellers if efficiency is critical. Other manufacturers, particularly targeting the agricultural pumping market, do not have the equipment or technology to properly polish

impeller passages. It is recommended that all new impellers be specified to have a C-10/C-20/C-30 finish.

The smoothing of pump bowls is somewhat different from smoothing of impellers.

1. Historically, the major pump manufacturers used porcelain enamel on their bowls. But this is now rare because:
    a. Most of the castings now come from overseas, often lacking porcelain enamel coating facilities.
    b. There is a movement to have NSF 61 approved coatings, and evidently porcelain enamel cannot meet the requirements for this stamp of approval.

2. Interestingly, many of the published efficiency curves were based on the old porcelain enamel lining, which was very smooth. If spray on epoxies is used, there are evidently 1-2 efficiency points lost compared to published curves. But with fusion bonded epoxy coating (see 3M Scotchkote 124 description below), the efficiencies will be as good as with porcelain enamel.

3. Based on interviews with pump dealers and manufacturers, it appears that the compounds below are the most popular smoothing applications for bowls and column pipes. They are listed below with a few pertinent comments.

    - Belzona. There are about 60 different types of this hydrophobic coating. It appears to be primarily used on reconditioning projects.
        - Belzona personnel travel to the job site and decide correct type of Belzona to use
        - Coating is applied on site, stays stuck very well, may chip if dinged, but will not peel; chips stays localized.
        - Apparently this has a long life – one pump coated in the 1960's was claimed to be in excellent condition in 2007, but the details are not known.
        - Material self-levels itself when being applied, producing a very smooth finish.
    - Powder coating with 3M Scotchkote 134 Fusion Bonded Epoxy Coating. This appears to be the "standard" that other products attempt to meet, and is common on new bowls.
        - This is a one-part, heat curable, thermosetting epoxy coating, which is one of the most popular "powder coatings" used by manufacturers of pumps.
        - It is NSF approved for potable water.
        - The epoxy is applied to pre-heated steel as a dry powder which melts and cures to a uniform coating thickness. It can be electrostatically applied to unheated metal parts and subsequently cured by baking. No primer is required.
        - The coated material must be able to withstand 400-deg temperature.
    - Flash chrome is a very thin layering. It does not obstruct waterways, and fills holes in bronze. It is reputed to last a long time, and also reduces sand wear.
    - Glass lining. Glass coating is only for the bowl – not a coating for the impeller. Glass lining is often recommended for smaller bowls (less than 18" diameter), as opposed to various epoxy materials.

In summary, new bowl assemblies for pumps with large hours of operation should be specified to have fusion bonded epoxy coatings, or glass linings. The estimated improvement in

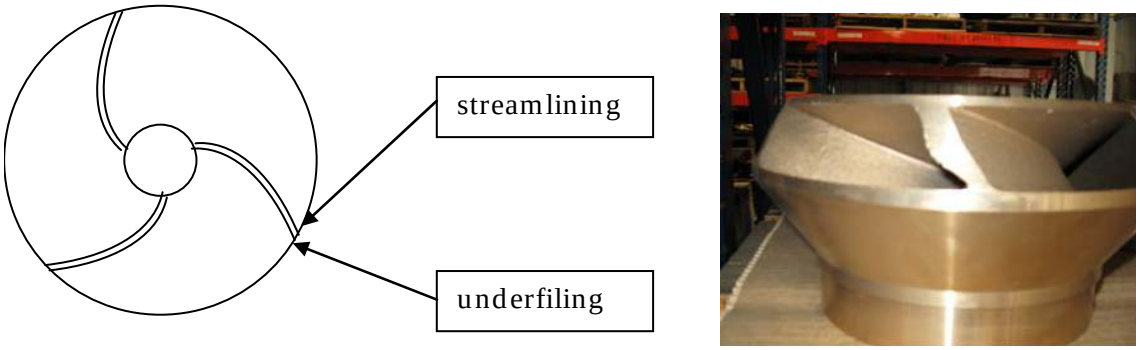
efficiency is 1-2%. The cost for a typical agricultural vertical pump bowl (10″ – 14″) would be about $500 - $650/stage, and about $300 for a horizontal pump. The economics on a horizontal pump, which has only one stage, are much more attractive than for vertical pumps with multiple stages.

Underfiling and streamlining

The exact details of these procedures, and whether they are desirable, should be left to the discretion of the manufacturer. However, it is recommended that any new pump should be specified to have no obvious burrs on the machined surfaces of the impellers or bowls.

- Both procedures involve filing burrs on the machined vane of the impeller.
- Streamlining entails filing the opposite side of the impeller than underfiling.
- Both underfiling and streamlining will improve efficiency and will aid in maintaining operating consistency. This occurs mainly due to reduced shock losses at the exit of the impeller. Due to the steeper discharge angle, the location of the BEP will also move out to a higher flow rate.
- The exact technique and/or angles that manufacturers use to underfile is somewhat of a 'trade secret'.
- Thinner blades have higher efficiencies, but they have less life span.

Figure 34: Thin part towards the bottom of the vane on the upper right photo has the correct thickness. The upper burrs (appearing as a thicker vane) need to be filed off.



Source: Irrigation Training and Research Center

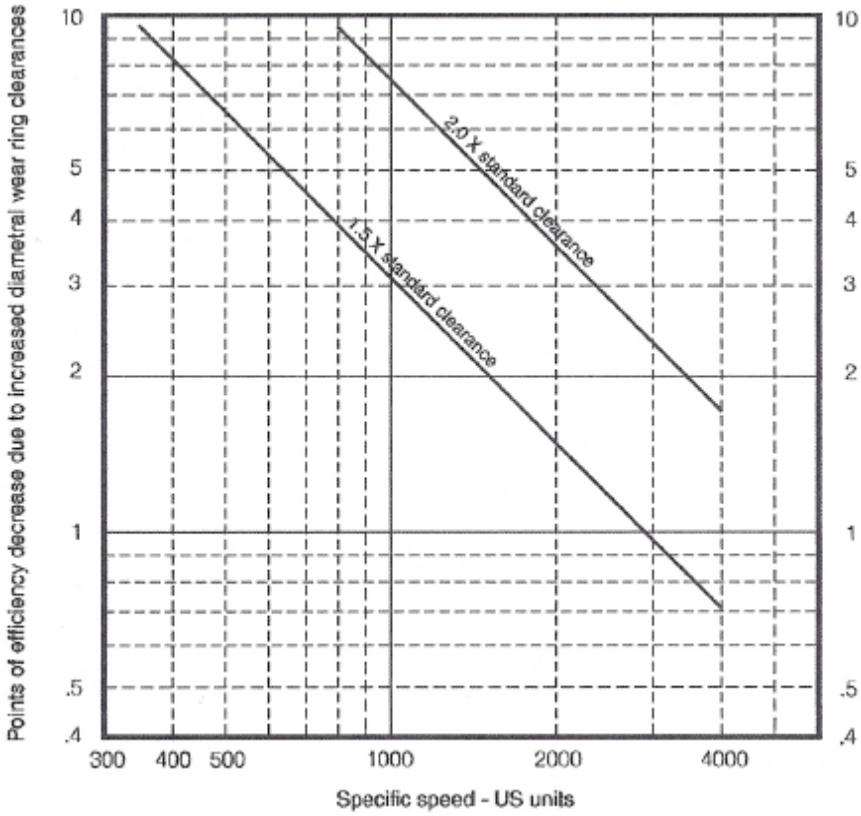
Figure 35: Machined impellers. The one on the left has been underfiled, and the one on the right still has burrs on it.

Source: Irrigation Training and Research Center

Wear rings

Impellers are centered in the pump casing (volute or bowl) with bearings. There must be a small clearance (not a bearing) between the impeller and the pump casing to allow the impeller to rotate freely. Some wear or erosion will occur at the point where the impeller and the pump casing nearly come into contact. This wear is due to the erosion caused by liquid and particulates flowing through this tight clearance from the high pressure side to the low pressure side. As the clearances become larger due to wear and the rate of leakage increases, the pump efficiency drops. This is illustrated in Figure 36.

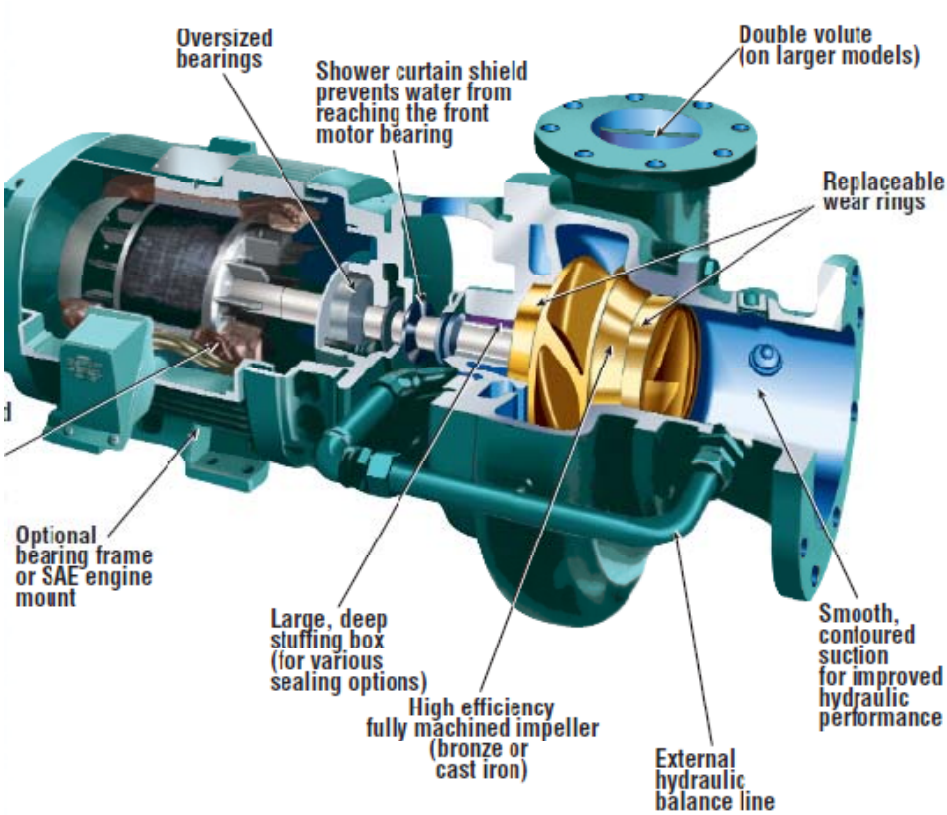
Figure 36: Estimated efficiency decrease due to increased wear ring clearance. (Figure 1.78B in HI Centrifugal Pump Design and Application – 2000)



Source: Irrigation Training and Research Center

This location of the close tolerance section is illustrated below for a horizontal end suction pump, as seen by the designation of "wearing rings."

Figure 37: Location of "wear" rings on a horizontal booster pump. Courtesy Cornell Pump. Note that this design has wear rings on both sides of the impeller.



Source: Irrigation Training and Research Center

The wear rings shown in Figure 37 special replaceable rings that are attached to the pump impeller. With vertical pumps, they are usually attached to the bowl itself, although sometimes they are also found on the impellers. Vertical turbine pumps can have wear rings on both the top and bottom of the impeller, although they are most common on the suction (bottom) side.

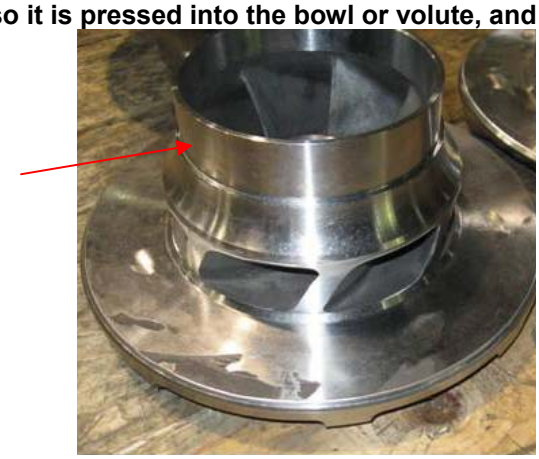
The idea of using wear rings is that if the close-tolerance surfaces are replaceable, they can be replaced periodically over the life of the pump without the more costly replacement of the impeller or casing.

Interviews with manufacturers and pump dealer/repair companies showed very conflicting sentiments regarding the use of wear rings. Some have strong feelings against wear rings, using the following arguments:

1. If the water is clean with no abrasives, installing wear rings is a complete waste of money.
2. By the time the wear rings have worn down to a noticeable extent, the bowl and impeller have also been worn down and need replacement.

On the other hand, it common for engineers to specify wear rings on new installations. Even here, there are differences in opinion as to what hardness the materials should have. Some manufacturers promote wear rings that are softer than the impeller materials; others promote wear rings that are harder than impeller materials. Others promote the use of hard materials for both of the wear surfaces. It seems most logical to use hard materials on both wear surfaces, but to avoid materials that will gall, such as stainless steel.

Figure 38: Fully machined impeller. Wear ring goes where arrow is pointing, on the inlet side. Ring is stationary, so it is pressed into the bowl or volute, and rubs on the impeller.



Source: Irrigation Training and Research Center

The cost to add double rings to a single stage of 10″ – 12″ vertical turbine will cost $100 - $300 for bronze materials, and $600 - $900 for harder materials.

Dynamically balancing of impellers (for vibrations)

Dynamic balancing of impellers is no different from dynamic balancing of car tires. Balancing should be to better than ISO 1940 Grade G 6.3 specs. The balancing is typically done by grinding small amounts of material from the heavy side of the impeller.

Figure 39: Dynamic impeller balancing equipment.

Source: Hines Industries, Ann Arbor, MI

Maintain a High Pumping Plant Efficiency

Devices/techniques that will help maintain low energy consumption:

1. Prevention of pump impeller/bowl wear
    a. New impeller materials
    b. Special linings
2. Prevention of bearing wear
    a. New oiler designs
    b. Special bearings and lubricant systems

Oil drip rate and oilers for vertical turbine pumps

Perhaps 70% of sudden failures of deep well vertical turbine pumps are caused by improper lubrication of motor bearings and lineshaft bearing problems. Use of newer bearing materials for water lubricated lineshaft bearings is discussed below. But most deep well pumps in agriculture have oil lubricated lineshaft bearings. There are three outstanding issues with the oil lubrication:

1. Most people do not know the proper drip rate.
2. The oil reservoirs are too small, so they may run out of oil before they are refilled.
3. Hardware that is sold does not provide for a constant drip rate over time.

Proper oil drip rate. Christensen (a division of Layne Christensen Co.) provides the following advice in its Deep Well Turbine Pumps manual:

Table 30: Oil drip rate

Shaft Diameter (inches)	Basic Drops per minute	Additional Drops per Minute per 100 ft. setting
.75 – 1.19	5	2
1.50 – 1.68	7	3
1.94 – 2.43	10	4
2.68 and larger	12	5

Source: Christensen Pumps O&M Manual Deep Well Turbine Pumps

Size of oil reservoir. A gallon of oil (size of many standard oil reservoirs) holds about 150,000 drops. This corresponds to about a 2 day to 2 week supply of oil in a typical one gallon oil reservoir. ITRC recommends using a reservoir holding a minimum of about 4 gallon.

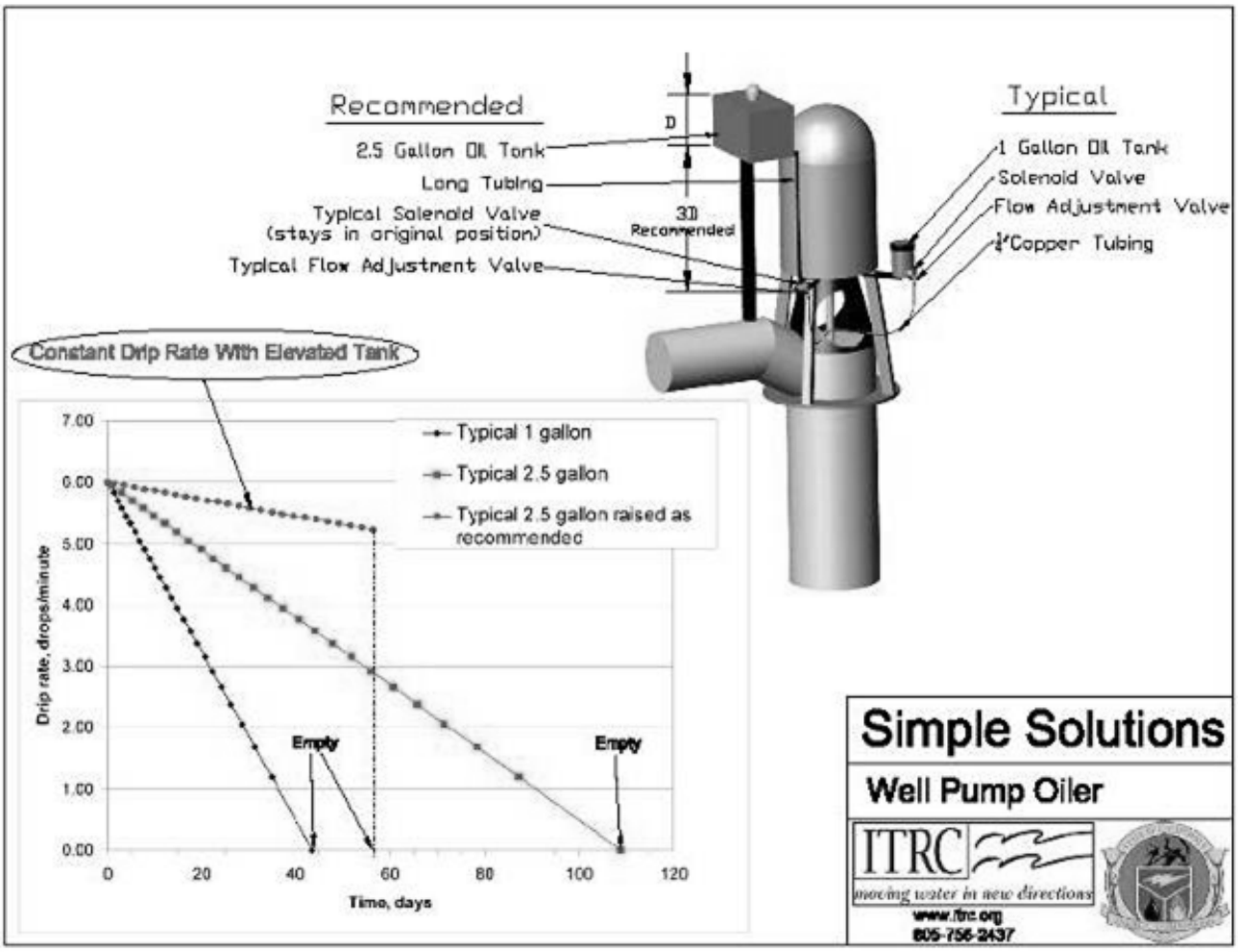
Maintaining a constant oil drip rate. Oil drip rates change over time for three reasons:

- The level of the oil in the reservoir drops, decreasing the pressure on the adjusting valve.
- The temperature of the oil changes, which changes the viscosity.
- The adjusting valve, or its entrance, becomes plugged.

A design by ITRC, shown in the following figure, overcomes all of these problems by:

- Raising the oil reservoir several feet above the adjusting valve. Therefore, a change in the oil level in the reservoir itself only represents a small percentage change in the total pressure on the valve.
- Some of the pumped water is circulated around the oil tube, immediately above the adjusting valve. This maintains a fairly constant oil temperature, regardless of air temperatures.
- The size of the oil reservoir is 4-5 gallons, so it does not need to be refilled as frequently as conventional oil reservoirs.
- The bottom of the oil reservoir is drainable, so sludge and contaminants and water can be removed easily.
- The intake pipe to the flow adjusting valve is located several inches above the floor of the reservoir, to minimize the chance of contaminants entering the adjusting valve.

Figure 40: ITRC well pump oiler



Source: Irrigation Training and Research Center

Lubricant types. Christensen recommends the following lubricants for pumps. Soy oil is also available for lineshaft lubrication.

Table 31: Recommended pump lubricants

RECOMMENDED LUBRICANTS		
	Grease for Lineshafts, Suction Bowl Bearings and Shaft Packings	**Turbine oils for Lineshafts, Suction Bowl Bearings and similar applications**
Operating Temperature Range	20° F to 120° F	20° F to 120° F
Required properties		
Pour Point :	20° F or lower (base oil)	20° F or lower
Flash Point :	300° F or higher (base oil)	300° F or higher
100° F Viscosity :	450 SUS or higher (base oil)	150 SUS or higher
ASTM Dropping Point :	160° F or higher	32
Nitrile Rubber Swell :	Minimal (up to 3%)	Minimal (up to 3%)
Thickener Type:	Calcium or Lithium	
Thickener Percent:	15% Minimum	

Manufacturer	Recommended Standard Industrial Lubricants	
Chevron Texaco Corp.	Chevron Ulti-Plex Grease EP2	Chevron *Hydraulic Oil AW32
	Texaco Novatex EP2	Texaco *Regal EP 32
CITGO Petroleum Corp.	Mystik Oil & Grease Mystik JT-6 Grease (5484)	Mystik Oil & Grease *Mystik Turbax Oil 32 (1812)
	Citgo Oil & Grease Premium Lithium EP2	Citgo Oil & Grease Pacemaker Oil 32
	Lyondell Lubricants Litholine HEP Grease	Lyondell Lubricants *Duro Oil 32
Fiske Brothers Refining Co.	Lubriplate 130AA Grease	Lubriplate *3V Oil
Exxon Mobil Corp.	Mobil Mobilux Grease EP2	Mobil DTE Oil 24
	Exxon Lodok EP 2	Exxon *Nuto H Hydraulic Oil 32
76 Lubricants Co.	76 Lubricants Multiplex EP Grease 2	76 Lubricants Hydraulic Oil AW/D 32
Shell Oil	Shell Alvania EP Grease 2	Shell *Tellus Plus Oil 32

**Note: In front of the oil grade means it is suitable for sub zero (F) temperature service.*

Manufacturer	Recommended Food Machinery Lubricants	
Chevron Texaco Corp.	Chevron #FM Grease EP2	Chevron *#Lubricating Oil FM32
	Texaco #Cygnus Grease 2	Texaco #Cygnus Hydraulic Oil 32
CITGO Petroleum Corp.	Mystik Oil & Grease #Mystik FG2 Grease (5607)	Mystik Oil & Grease #Mystik FG/AW 32 Oil (1931)
	Citgo Oil & Grease #Clarion FG HTEP Grease	Citgo Oil & Grease #Clarion FG AW Oil 32
	Lyondell Lubricants Ideal FG 2 Grease	Lyondell Lubricants #Ideal FG 32 Oil
Fiske Brothers Refining Co.	Lubriplate FML-1 Grease	Lubriplate *#FMO-200-AW
Exxon Mobil Corp.	Mobil #Mobil Grease FM102	Mobil DTE FM 32 Oil
	Exxon Foodrex FG 1	Exxon *Nuto FG Hydraulic oil 32
76 Lubricants Co.	76 Lubricants 76 Pure FM Grease	76 Lubricants 76 FM Oil 32

**Note: 1. In front of the oil grade means it is suitable for sub zero temperature (F) service.*
2. Food machinery lubricants meet USDA H-1 requirements and FDA document 21 CFR 178.3570. In addition, # in front of the product name means it is NSF 61 registered products.

Source: Christensen Pumps O&M Manual Deep Well Turbine Pumps

Lower discharge bearing. Mixed and axial flow pumps have a "lower discharge bearing" located immediately above the bowl assembly. Even if the other bearings are oil lubricated, this bearing is product lubricated. It is common practice to run a grease line from the surface down to this bearing on axial and mixed flow pumps because of their short setting and the fact that they are in sumps rather than in confined wells. The figure below shows a mixed flow pump being assembled with such a fitting.

Figure 41: Grease fitting to lubricate the discharge bearing of a mixed flow pump

Photo Credit: Irrigation Training and Research Center

Bowl Sump Bearing. Some low-lift (axial or mixed flow) vertical pumps have a bearing on the inlet bell itself. These are also grease lubricated in very sandy conditions. Vesconite bearings could also be used. The figure below shows a grease tube that supplies the bearing.

Figure 42: Grease tube to lubricate the bowl sump bearing

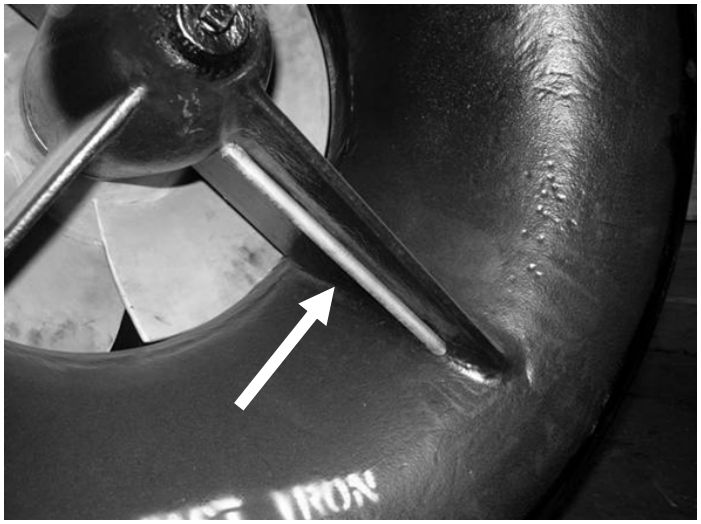


Photo Credit: Irrigation Training and Research Center

Wear on impeller and bowls

There are three types of wear that one may find on impellers:

1. Corrosion
2. Sand erosion
3. Cavitation

Cavitation problems can be solved with a proper pump and inlet design, so it is not discussed further in this section. It is interesting to note that a material that is resistant to cavitation may be poorly suited for sand wear resistance. Corrosion and sand wear problems can be minimized if the proper impeller and bowl materials are used, which is discussed below.

ITRC was unable to find any information regarding how pump performance degrades over time with sand wear with various materials and sand concentrations. ITRC is currently performing research on impeller/bowl sand wear, and corresponding pump performance. That research resulted from this PIER grant.

The table below provides some information regarding sand wear on different alloys.

Table 32: Typical impeller-tumbler wear data for ferrous alloys

Typical impeller–tumbler wear data for ferrous alloys (wear rates determined from 1-h tests)

Alloy and designation	Chemical composition	Hardness (BHN)	Volume loss (mm^3/h)
304 SS	18.9Cr–2.4Mn–8.0Ni–0.4Si–0.3Mo–0.3Cu	153	104.7
Gall Tough®[a]	0.1C–16.3Cr–5.5Mn–5.2Ni–3.5Si–0.1Mo–0.1Cu–0.1N	184	83.1
13% Mn Steel	1.1C–0.4Cr–12.8Mn–0.2Ni–0.4Si	201	78.2
ASTM A514	0.2C–0.5Cr–1.4Mn–0.2Ni–0.3Si–0.2Mo0.4Cu	269	94.7
18-18Plus®[a]	0.1C–17.4Cr–17.7Mn–0.4Ni–0.5Si–1.0Mo–1.0Cu–0.5N	315	90.5
REM 500	0.3C–1.1Cr–0.6Mn–0.3Si–0.2Mo	495	91.3
AISI 4340	0.4C–0.8Cr–0.7Mn–1.8Ni–0.3Si0.3Mo	515	89.7
HT-6A[b]	0.3C–19.6Cr–0.1V–7.2Fe (bal Ni)	597	188.2
D2 tool steel	1.6C–13.7Cr–0.5Mn–0.2Ni–0.4Si–0.8Mo–0.8V	608	69.5
White cast iron	3.2C–15.3Cr–0.8Mn–0.5Ni–0.4Si–1.0Mo	698	67.1
CHW-45[b]	2.1C–5.4Cr–0.2Ni–1.5Mo–1.1V	709	106.6
AISI 1060	0.8C–0.4Mn	716	63.9
MS-5A[b]	0.9C–15.2Cr–5.4Ni–3.8Mo–4.8Co–0.1V	772	109.4
CM[b]	2.3C–11.1Cr–0.2Ni–2.8Mo–0.1V	852	73.3
C[b]	2.7C–2.9Cr–0.2Ni–3.1Mo–0.1V	990	46.3

[a] The Gall Tough® and the 18-18 Plus® are nitrogen-containing stainless steels produced by the Carpenter Technology.
[b] These materials are the Ferro-Tic® line of TiC reinforced composites produced by Alloy Technology International (HT-6A is a Ni-based matrix, while the others are Fe-based).

Source: Wilson, R.D. and J.A. Hawk. 1999. Impeller Wear Impact- Abrasive Wear Test. Wear (225-229). Pp 1248-1257. Published by Elsevier

Relative prices of various materials are given in the table below. A "typical" agricultural irrigation well pump impeller in California will weigh about 25 pounds.

Table 33: Relative prices of various impeller materials

Material	$/lb in 2010	Cost difference for a 25 lb impeller
Cast Iron	1.95	
Ductile Iron 65-45-12	3.54	
Ductile Iron 100-70-03	2.96	
Bronze	9.01	0
316 Stainless Steel	7.50	-38.
CD4MCU Stainless Steel	10.51	+ 38.
Super Duplex Stainless (v. high chrome)	22.82	+ 345.

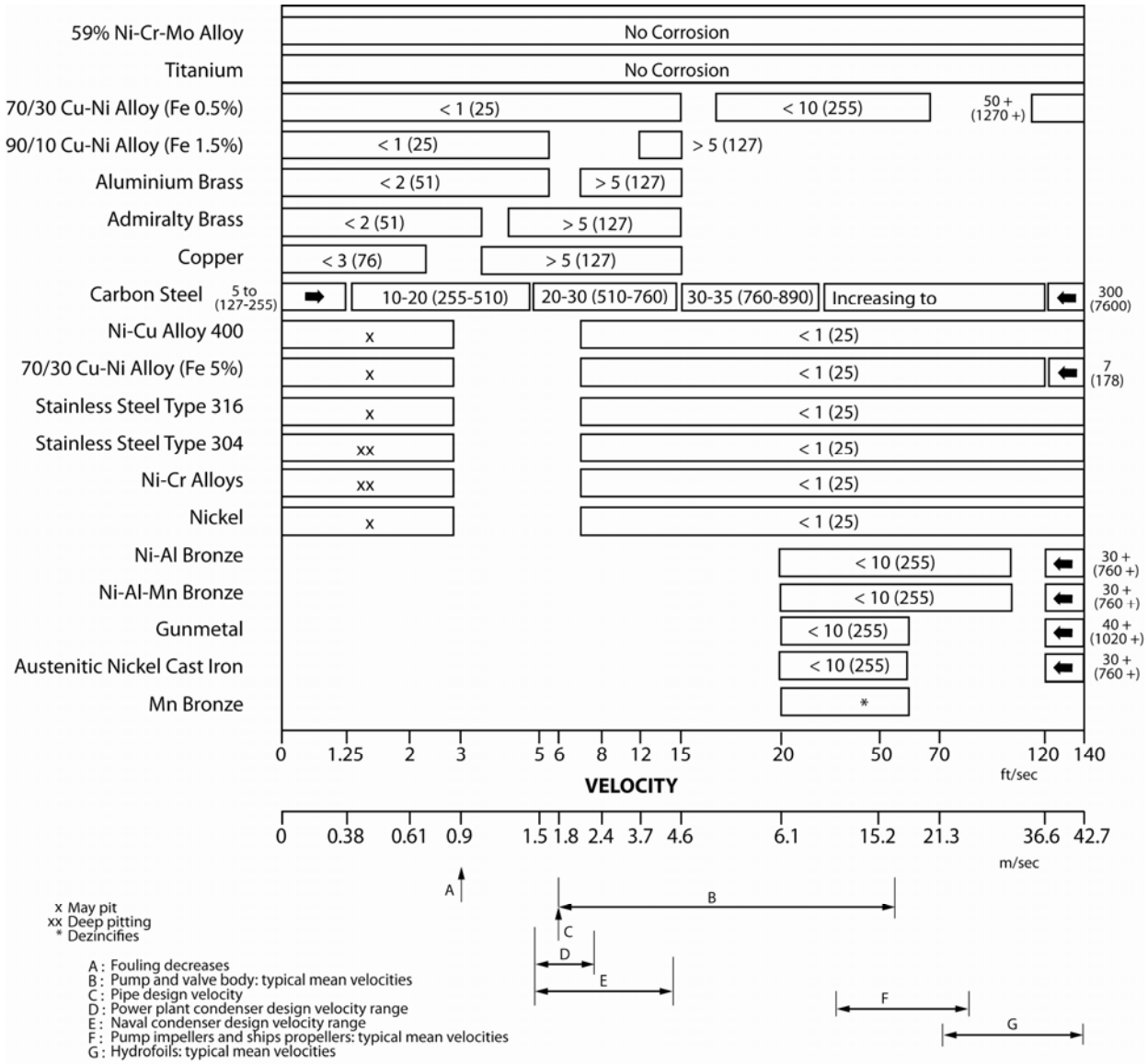
Source: Irrigation Training and Research Center

Evidently, most published pump curves, unless stated otherwise, are based on some type of bronze as the impeller material. SAE 40 red brass, SAE 63 zincless bronze, silicon bronze, aluminum bronze, or Ni-Al-bronze all have about the same smoothness, which means no difference in the efficiency of the impeller (not bowl). All of the iron materials (cast iron, ductile iron, and Ni-Resist) all have a much rougher finish. Therefore, unless they are carefully polished, they will typically have 1-2 percentage points drop in efficiency compared to published data. Stainless steels have the same roughness problem, but they have an additional challenge in that the castings come out a bit smaller than with other materials, so the actual head and flow are a bit lower than published if the manufacturer is not a top-end manufacturer who publishes special curves or modifies the casting process.

As prices of materials have come closer, there is less cost difference between materials. Therefore, some companies are switching to standard stainless steel impellers. Many people believe that if there is a sand problem a hard iron should be selected over any bronze allow (such as aluminum bronze).

Corrosion is not a major factor in most of California, with the exception of some areas near the ocean. Table 34 provides information regarding common pump component materials and their resistance to corrosion.

Table 34: Relative corrosion of various materials available for use in pumps.



NOTE: Approximate corrosion rates are given by the figures on the bars and expressed in units/hr as mils/yr (microns/yr)

SOURCE: (INCO) International Nickel Company
NIDI Publication 12007 [Copper-Nickel Alloys - Properties and Applications (12007) Published by Copper Development Association, in co-operation with the Nickel Development Institute, 1982.]

Source: Irrigation Training and Research Center

Chapter 3: Stage 2: Research Key Irrigation System Components and Potentials for Energy Conservation

To accomplish the objectives of Stage 2, the following steps were taken:

1. A literature and web search was performed.
2. Seventeen pump dealers from throughout California were interviewed.
3. Physical visits were made to 5 pump manufacturer facilities to discuss new pump features.
4. Meetings and interviews were held with many of the manufacturers of irrigation equipment during three annual trade shows of The Irrigation Association (in Phoenix (2007), Anaheim (2008) and San Antonio (2009).
5. A request for information on research was e-mailed to key irrigation researchers nation-wide.

Most of the results of Stage 2 are incorporated into the information found in the earlier Stage 1 report.

Seventeen different pump companies, from different counties in California, were interviewed on several different topics that relate to the efficiency and life of a pump. Their ideas and suggestions are analyzed and summarized below. Although the causes of inefficiency on a pump are known, very few people had suggestions or ideas on how to eliminate or lessen their effect on its efficiency.

Table 35: Recommendations from Pump Dealers

Recommendation	Number of People
Clean wells	13
Variable frequency drive (VFD)	12
Maintain bearings greased	11
Keep oiler filled and correct drop rate	11
Pump test	10
Premium efficiency motors	6
Properly size the pump	5
Bigger column pipe size	2
Soft start for motor	2
Submersible pump	2
Right size wiring	1
PVC casing	1
Keep motors dry and clean	1
Wear rings	1
Epoxy coat impellers	1

Source: Irrigation Training and Research Center

The five pump manufacturers visited were Peerless, Berkeley, Cornell, Weir-Floway, and Cascaade. The most interactive discussions were held with Pentair vertical pump personnel (Fairbanks Morse), the factory of which was not visited.

Meetings were held with individual manufacturers of most agricultural irrigation equipment (that impact horsepower requirements) at the various Irrigation Association meetings. There was also excellent cooperation by four of the manufacturers in providing filters for testing. The general response of most manufacturers is a combination of the following:

1. Willingness to promote perceived energy benefits and attributes of products that they have for sale at the moment.
2. Unwillingness to brainstorm new concepts if those ideas will be released to the public.
3. Sales emphasis on details that are relatively unimportant. For example, having a relatively lower friction loss (of less than 0.5 psi difference) compared to a competitor is claimed to be a huge advantage by one manufacturer – without considering differences in uniformity of backflush, loss through backflush valves, etc.

In other words, the meetings were valuable to assess what products are currently available, but not for brainstorming from a technical sense.

The request for new ideas from national irrigation equipment researchers, even with the promise of funding (as originally envisioned in the contract), did not produce new ideas.

Chapter 4: Stage 3

Stage 3a: Discuss Rebate Plans with Utilities and State Agencies

ITRC held face-to-face discussions with PG&E and Southern California Edison personnel several times to discuss the issues starting in 2009 and continuing until the end of the contract. Beau Freeman from ITRC attended a CPUC meeting in San Francisco, which was followed up by a letter to utility and CPUC personnel about the possibility of beginning some type of "ENERGY STAR" program. ITRC received positive replies throughout the interactions.

ITRC found that there are substantial challenges to be faced when beginning new rebate programs. These include:

- The utilities have a multi-year process for approval of any new rebate program, which must then be approved by the CPUC. This single factor eliminated any implementation of a new rebate program, because the knowledge that would be put into the rebate program development was gained during the research project. That is, at the beginning of the research project there was insufficient knowledge and focus to adequately identify the best potential rebate programs.
- The existing rebate programs are rather simple – such as providing funding for pump repair or installation of a drip system. In contrast, this PIER research program took a more complex approach to the problem. This PIER research program focused on ingredients or specifications that would make a pump repair most effective, for example – rather than focusing on increasing the number of pumps being repaired. It is a fundamentally different approach and will take time to receive adoption. This PIER research project proposes to attach performance standards to a new drip system, for example – as opposed to supporting drip systems that may inherently have higher-than-necessary pressure requirements or poor distribution uniformity.

ITRC is looking forward to working with the utilities in the future to help shape a new generation of incentive programs.

Stage 3b. Develop Standards With Manufacturers

The early idea was to develop testing procedures for various irrigation components, such as media tanks. An associated idea was that manufacturers would be supportive of performance standards that would ensure high quality and high performance of various components. This idea proved to be unrealistic.

The irrigation component manufacturing industry is being consolidated into approximately 5 large companies – each of which is rapidly purchasing numerous smaller component manufacturers. Each major manufacturing company claims to have to best equipment, with largely anecdotal evidence to back up the claims. There are, of course, major differences between the qualities and characteristics of various emitters, filters, valves, hoses, etc. But a hard look at a whole range of valves, for example, will show that many of the valves are inferior. This can be damaging to sales.

There is no incentive for the companies to participate in standards unless they are confident that their individual products will be rated the highest. Because the major companies have purchased numerous product lines with vastly different histories and qualities, there is no company that has a uniform and complete arrangement of vastly superior products.

Historically, the irrigation industry has been very satisfied with superficial testing of products. For example, pressure compensating emitters are tested for the manufacturing coefficient of variation of discharge – widely accepted test. But the manufacturers send emitters of their choice to the testing labs and designate what pressure range should be tested. Important additional tests such as how the emitters perform over time, and whether they have hysteresis, are not performed and publicized.

Another example is sprinkler testing. It is common for manufacturers to pay a testing lab to conduct a simple indoor test of the overlap pattern of water droplets on the ground. It is easy to display the results graphically – making a very neat and convincing sales package. The fact that the overlap patterns are completely different in the wind is disregarded.

There are, of course, excellent engineers and company executives who continually strive to improve products and to market products of high quality. While ITRC is doubtful that meaningful benchmarks will be adopted by the irrigation industry as a whole, the progressive executives will, in the future, seek more meaningful and complete testing to prove that their high quality products are indeed better than those of competitors.

In other words, the movement toward higher expectations will come from individual manufacturers who have excellent products, rather than from manufacturers as a unified group.

Meaningful rebate and incentive programs will also be key towards improving quality. The utilities should definitely change from paying for "pump repairs," "pump replacement," or "drip system installation" to instead having programs that pay for specific performance. The white paper regarding low pressure drip system rebates describes a meaningful rebate. Without such performance standards, there is no incentive (except for pride and integrity) for pump and irrigation dealers to strive to supply very high quality equipment that reduces energy consumption.

Stage 3c. Irrigation Component Testing Facility

Area for Research

An 80′ by 20′ concrete slab on grade was constructed at the ITRC Water Resources Facility for the purpose of allowing multiple projects to utilize a clean and safe environment. Situated on the banks of the Drumm Reservoir (Figure 43), the concrete slab and its engineered drain system permit high flow rate testing without the possibility of excessive erosion or muddy conditions. Such a feature affords the ITRC multiple possibilities for future projects and research.

Figure 43: Concrete slab next to the Drumm Reservoir

Photo Credit: Irrigation Training and Research Center

During the monolithic slab's construction, multiple sections of conduit were laid to safely expand the electrical and data acquisition options for future testing. Integrating the current loops of pressure transducers and flow meters into Programmable Logic Controllers (PLCs) can be easily accomplished due to the forethought of installing NEMA 4 enclosures housing terminal blocks and 110V receptacles every twenty feet down the slab (Figure 44).

Figure 44: NEMA 4 enclosures and 110VAC receptacles

Photo Credit: Irrigation Training and Research Center

A variety of electrical panels distribute single- and three-phase power to the slab and the surrounding area (Figure 45). The ability to run multiple three-phase and single-phase pumps simultaneously and in many configurations dramatically increases research opportunities.

Directly next to the electrical control panels is an enclosure housing a PLC and a Human Machine Interface (HMI). The PLC (Figure 46) coupled with the pre-installed conduit and terminal blocks enhances the adaptability of data logging during research efforts.

Figure 45: Electrical panels

Photo Credit: Irrigation Training and Research Center

Figure 46: Installed PLC

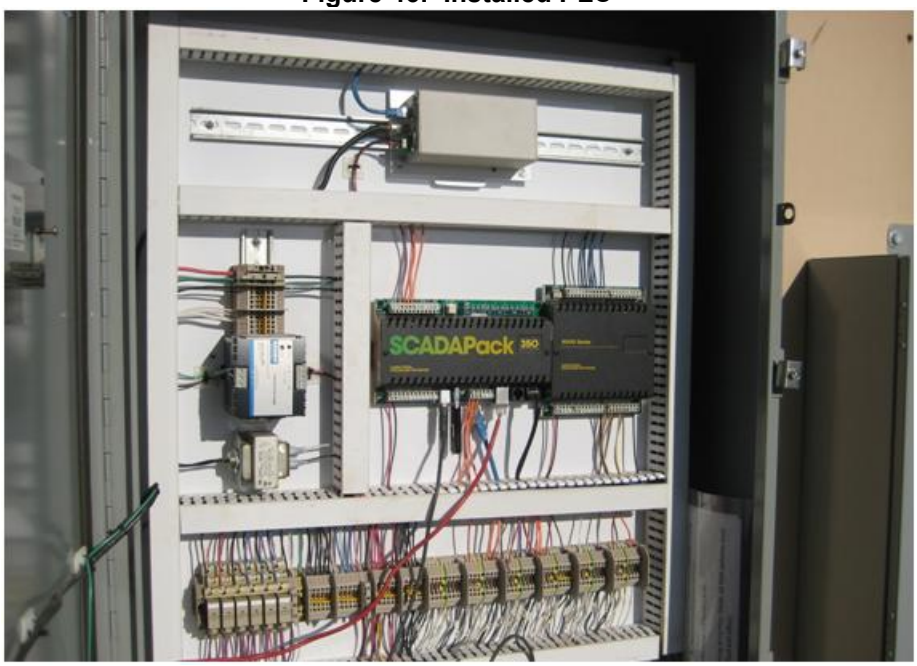


Photo Credit: Irrigation Training and Research Center

Sand Media Filter Research

The first project situated upon the slab was focused on comparing multiple sand media filter products and their relative performance (Figure 47). Characteristics of operation were compared such as: pressure loss through the filter during normal operation and backflush; backflush frequency; filtration performance; and concentration of sand during backflush.

Figure 47: Sand media filter research

Photo Credit: Irrigation Training and Research Center

The various filters were then testing without lids to further investigate backflush uniformity. A demonstration was set up to highlight characteristics of six different designs for a California Agricultural Irrigation Association (CAIA) tour on September 29, 2010 (Figure 48).

Figure 48: CAIA backflush demonstration

Photo Credit: Irrigation Training and Research Center

The facility was used to test various sand media tank components such as backflush valves (Figure 49**)**. A large portion of this testing was completed on the slab to take advantage of the pre-installed data acquisition system and the high flow drains. Of the backflush valves that were tested, there existed many combinations of sizes and connection types. In order to physically install each valve onto our test setup, numerous adapters were required.

Figure 49: Backflush valve internals

Source: Irrigation Training and Research Center

Every adapter was purchased or fabricated (Figure 50) out of steel so that they may be used for countless future tests (Figure 51). This stockpile of different adapters can now streamline future research efforts by minimizing assembly and setup time.

Figure 50: Machining a grooved fitting

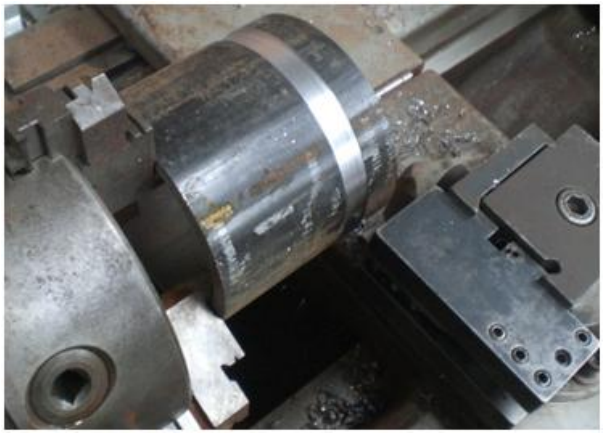


Photo Credit: Irrigation Training and Research Center

Figure 51: Adapter collection

Photo Credit: Irrigation Training and Research Center

Valve Testing

The concrete pad and adapters described above have now been used in tests comparing performance characteristics of various manufacturers' pressure regulating valves and pressure relief valves (Figures 52 and 53).

Figure 52: Measuring pressure on 4" pressure regulating valves

Photo Credit: Irrigation Training and Research Center

Figure 53: Utilizing concrete pad and adapters for valve testing

Photo Credit: Irrigation Training and Research Center

Sand Wear Testing

As a result of the PIER research on pump materials and efficiency, Southern California Edison has commissioned ITRC to utilize the testing facility to compare different materials' resistance to sand wear in vertical turbine pump impellers and bowls (Figure 54). The sandy water (minimum 200 ppm sand) circulates continuously as the water horsepower output is compared to the electrical input to the motor through a datalogging PLC (Figure 55). Impeller materials such as stainless steel and a nickel aluminum bronze alloy will then be compared to the standard of bronze impeller for the extremity and rate of sand wear.

Figure 54: Sand wear testing at the ITRC's Water Resources Facility

Photo Credit: Irrigation Training and Research Center

Figure 55: PLC datalogger and touchscreen

Photo Credit: Irrigation Training and Research Center

Weighing Tank

The test facility takes advantage of ITRC's in-house weighing tank, accurate to 0.25%, for water flow rate verification. Water can enter the elevated flume from various sources, spilling then into the weighing tank (Figure 56) via a pneumatically operated valve (Figure 57).

Figure 56: Water flowing to weighing tank through air valve

Photo Credit: Irrigation Training and Research Center

Figure 57: Pnuematic controls

Photo Credit: Irrigation Training and Research Center

The water is then collected in the weighing tank where the weight is measured by four load cells. The load cell output is then logged over time and converted to a volume. The PLC (Figure 58) then automatically calculates the flow rate and displays it through a Human Machine Interface (HMI). The ability to accurately measure flow rate allows the ITRC the ability to compare a wide range of open channel and pipeline flow measurement devices at large and small flow rates.

Figure 58: Weighing tank PLC datalogger

Photo Credit: Irrigation Training and Research Center

Vortex Testing

Another new project sponsored by SCE as a result of the PIER research results involves research and demonstration correct pump sump designs to inhibit vortexing (Figure 59). Pump sump characteristics such as floor to suction bell clearance, suction bell submergence, and pump to back wall distances are being investigated.

Figure 59: Adjustable False floor and false wall in pump sump

Photo Credit: Irrigation Training and Research Center

Furthermore, skewed and straight intake velocity profiles are being tested by altering the perforated intake wall (Figure 60) to showcase the propagation of vortexes and fragility of laminar inlet flows.

Figure 60: Perforated intake wall setup for straight intake

Photo Credit: Irrigation Training and Research Center

Chapter 5: Stage 4: Begin Testing and Assignment of ENERGY STAR Label

Important advancements were made during this research project for the assignment of an ENERGY STAR Label for energy-conserving agricultural irrigation products. These components are discussed below.

Media Tanks. ITRC staff constructed the testing facility to begin testing of irrigation components. Appendix 3A provides details of testing for sand media filter tanks. This was the most comprehensive testing of media tanks that ITRC is aware of. It was highly publicized among the irrigation dealers throughout California, and has been well received by them.

The lessons learned from the sand media filter tank testing were:

1. With these devices, the performance is much more complex than simple measurement of pressure requirements. It also involves the adequacy/effectiveness of filtration.
2. None of the filters could be given uniformly high ratings. Rather, the testing showed what the desirable characteristics should be. This is important – the original idea was to rate individual filters. The result was a listing of desirable characteristics which are already being used by some of the manufacturers (based on confidential personal conversations) to improve their filter designs.
3. Some of the manufacturers were very insistent about focusing on one or two good aspects of their filters, at the complete expense of other important features that were lacking in their designs. It was apparent that they were not looking for a complete, unbiased analysis of media filters.
4. Besides providing guidance to manufacturers regarding desirable design characteristics, the testing showed that it is indeed possible to effectively use sand media tank filters at lower pressures than many designers believe.

The fourth point is of high significance, and the result is a white paper (Appendix 3D) for the California utilities to consider in developing a new incentive program for low pressure drip/micro-irrigation systems. Appendix 3D provides a systems approach by requiring no more than a specified pressure, and a design for excellent uniformity of water distribution. Those requirements, of course, cannot be met unless the dealer uses good filters, good valves, and excellent design techniques. In addition to the testing on sand media filters and based on this PIER research project, SCE has funded testing on the impact of sand wear on pump impellers.

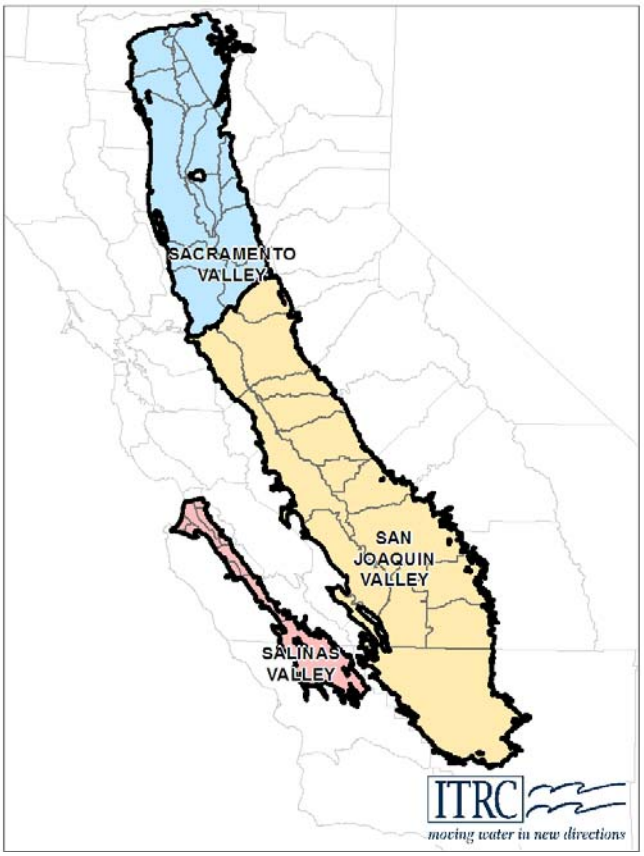
The second white paper (Appendix 3E) is designed to increase the adoption of variable frequency drive (VFD) controllers. While it is true that VFD controllers have been promoted by the utilities in irrigation for some time, the white paper provides a more complete systems approach to the justification for a rebate program than has been used in the past.

The Stage 1 part of this report mentions a variety of other excellent selections for future rebate programs. At this point in the research, an Energy Wise Label program has been shown to be feasible with considerable more coordination with the utilities and manufacturers. ITRC is poised to help expand this effort in the future.

One major discussion point for the California utilities was the incorporation of pump irrigation performance characteristics as a prerequisite for the ENERGY STAR Label. The detailed discussion for the pump performance is included in the next section of this report.

Pump Performance Characteristics. Pumping data was collected from over 15,000 well and non-well pumps throughout the Sacramento, Salinas, and San Joaquin Valley groundwater basins of California. Each of these basins is divided into a number of subbasins. A map of the general layout is shown below (gray lines outside of basins represent county lines; gray lines inside basins represent subbasins).

Figure 61: Groundwater basins in California.



Source: Irrigation Training and Research Center

Data was analyzed by basin and subbasin for well pumps and non-well pumps. For each pump type, averages were calculated based on:

- The whole basin
- Overall pumping plant efficiency (OPPE)
- kWh/AF
- Subbasins

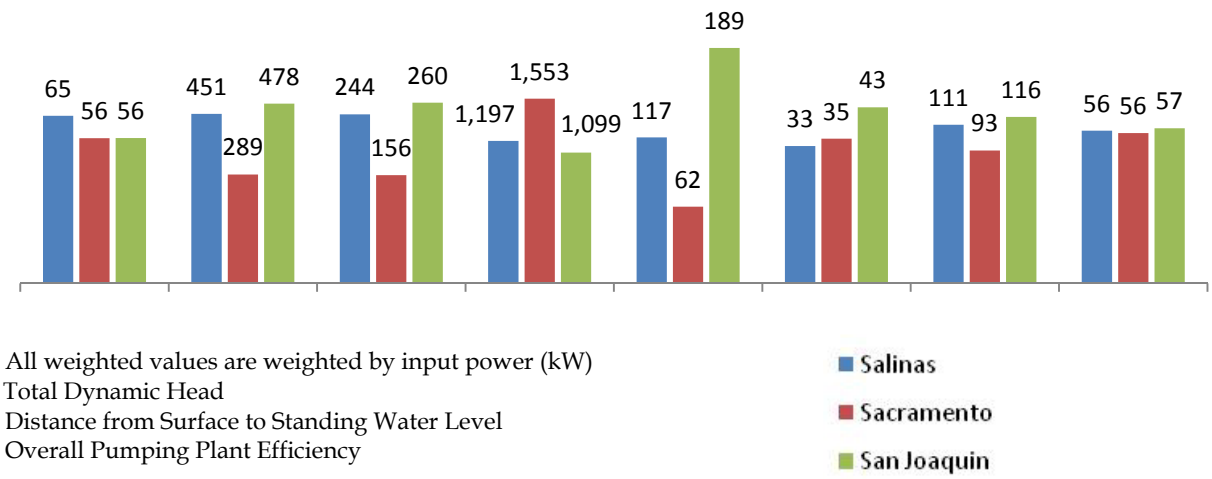
General conclusions were drawn for each set of averages, and a final summary of conclusions is given at the end of each pump type section. An additional analysis that is more pertinent to future pump test programs can be found in Appendix 3B.

Well Pump Subbasin Comparisons

Over the three groundwater basins, 12,876 well pump tests were performed. The following table summarizes the averages of a variety of factors from well pump tests in each of the three groundwater basins.

Table 36: Summary of regional well pump test data.

Average Input Power [kW]	Average Weighted[1] kWh/AF	Average Weighted[1] TDH[2] [ft]	Average Weighted[1] Flow Rate [GPM]	Average Weighted[1] SWL[3] [ft]	Average Weighted[1] Drawdown [ft]	Average Weighted[1] Motor HP	Average Weighted[1] OPPE[4] [%]



[1] All weighted values are weighted by input power (kW)
[2] Total Dynamic Head
[3] Distance from Surface to Standing Water Level
[4] Overall Pumping Plant Efficiency

Source: Irrigation Training and Research Center

When comparing the data from the three basins, some general observations regarding the well pump data can be made:

1. All three basins have very similar average OPPE (~56%).
2. The Salinas basin's well pump tests had a slightly higher average input power than the well pump tests in the other basins.
3. The Sacramento basin's well pump tests had a higher average flow rate and lower average kWh/AF, total dynamic head, motor HP, and depth to standing water level than the well pump tests in the other basins.
4. The San Joaquin basin's well pump tests had a greater average depth to standing water level and average drawdown than the well pump tests in the other basins.

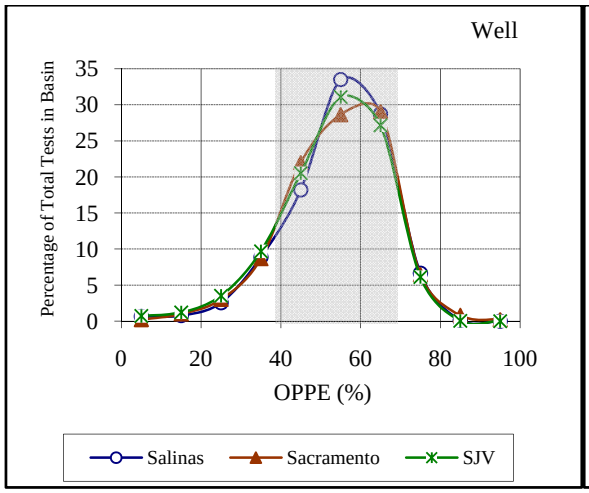
Regional Comparison by Overall Pumping Plant Efficiency (OPPE)

The data for each basin was compared with overall pumping plant efficiency (%) to:

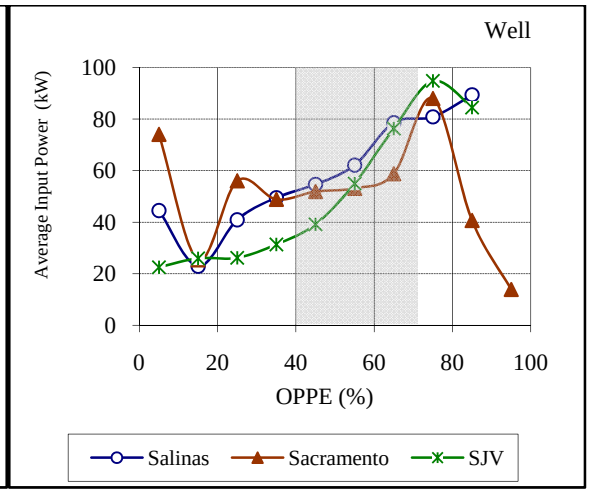
- Test Distribution (Graph 1)
- Average Input Power [kW] (Graph 2)
- Average kWh/AF (weighted by input power) (Graph 3)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power) (Graph 4)
- Average Flow Rate [ft] (weighted by input power) (Graph 5)
- Average Depth to Standing Water Level (SWL) [ft] (weighted by input power) (Graph 6)
- Average Drawdown [ft] (weighted by input power) (Graph 7)
- Average Motor HP (weighted by input power) (Graph 8)

The values are grouped into 10% ranges, with the point at the midpoint of the range (for example, the average value for the 21-30% range is placed at the 25% point). The grayed areas show the ranges where a majority of the values lie.

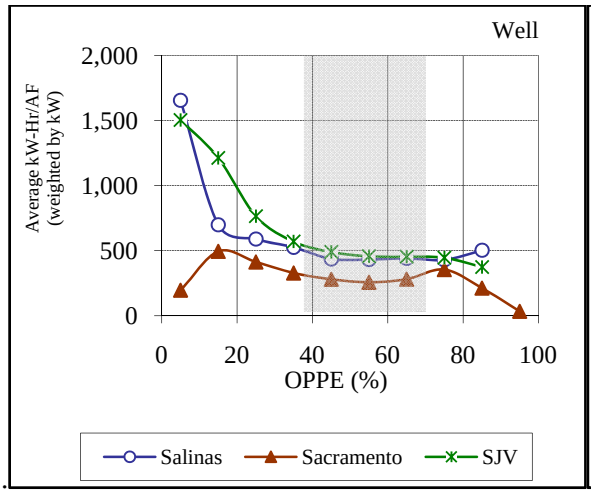
Graph 1: Test distribution.



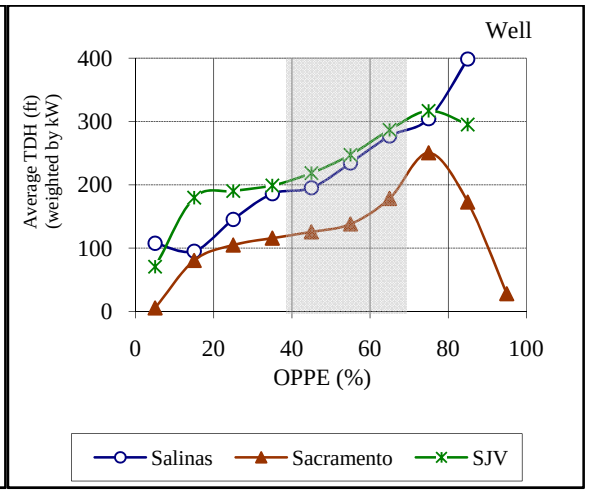
Graph 2: Average input power [kW].



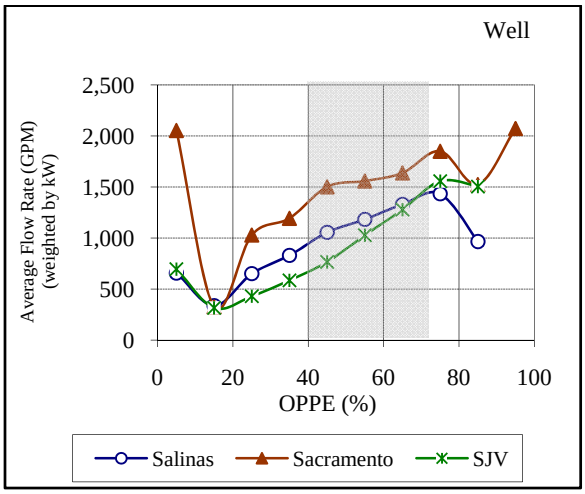
Graph 3: Average kWh/AF (weighted by input power)



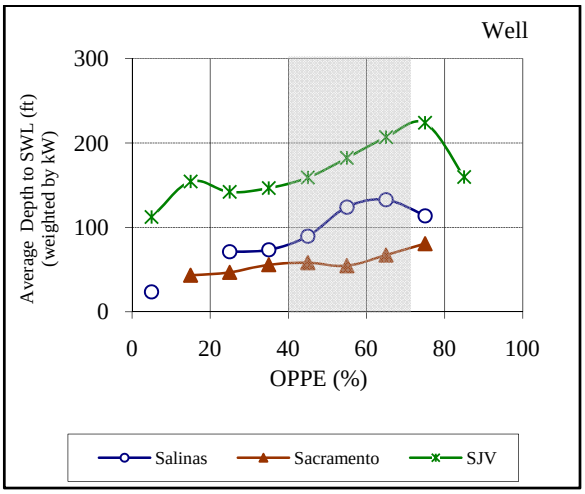
Graph 4: Average total dynamic head (TDG) [ft] (weighted by input power).



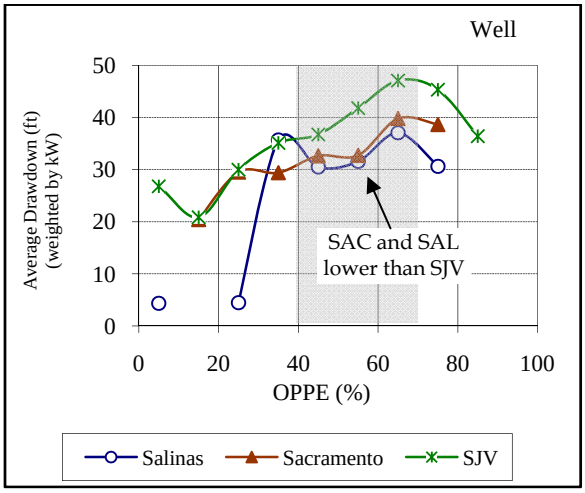
Graph 5: Average flow rate [GPM] (weighted by input power).



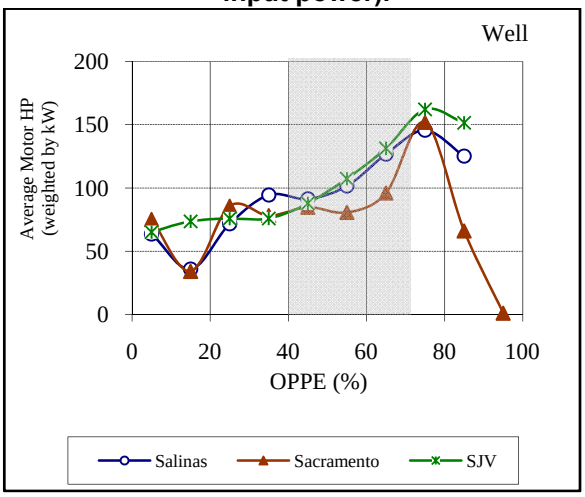
Graph 6: Average depth to standing water level (SWL) [ft] (weighted by input power).



Graph 7: Average drawdown [ft] (weighted by input power).



Graph 8: Average motor HP (weighted by input power).



Source: Irrigation Training and Research Center

When comparing the data from the three basins to the overall pumping plant efficiency, some general observations regarding the well pump data can be made:

1. A majority of the well pump tests fall between the 40-70% overall pumping plant efficiency ranges.
2. Across nearly all of the overall pumping plant efficiency ranges, the Sacramento basin's well pump tests have a higher flow rate, and a lower kWh/AF and total dynamic head than the well pump tests in the other basins.
3. The San Joaquin basin's well pump tests had higher average drawdown values than the well pump tests in the other basins.
4. The average depth to the standing water has a lot of variation between basins.

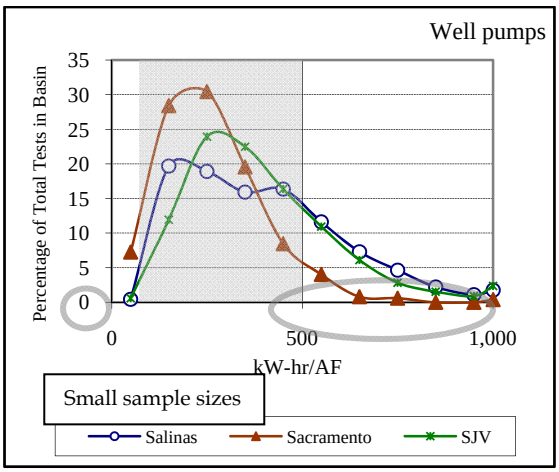
Regional Comparison by Energy Consumption Per Volume Pumped

The data for each basin was compared with kWh/AF to:

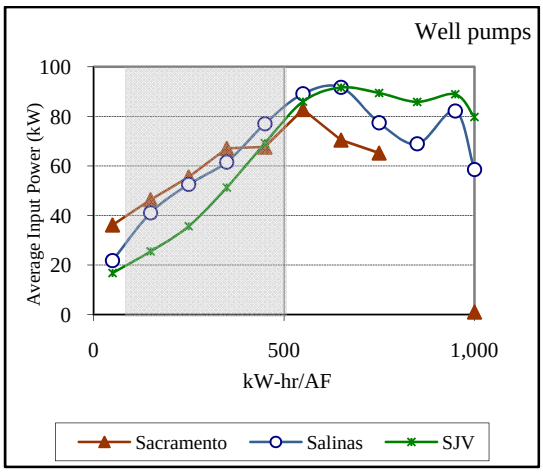
- Test Distribution (Graph 9)
- Average Input Power [kW] (Graph 10)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power) (Graph 11)
- Average Flow Rate [ft] (weighted by input power) (Graph 12)
- Average Depth to Standing Water Level (SWL) [ft] (weighted by input power) (Graph 13)
- Average Drawdown [ft] (weighted by input power) (Graph 14)
- Average Motor HP (weighted by input power) (Graph 15)
- Average Overall Pumping Plant Efficiency (OPPE) [ft] (weighted by input power) (Graph 16)

The values are grouped into ranges of 100 kWh/AF with the point at the midpoint of the range (for example, the average value for the 201-300 kWh/AF range is placed at the 250 kWh/AF point). Each basin had a single data point placed at 1000 kWh/AF that represents the y-axis average value for all data points greater than 1,000 kWh/AF. The grayed areas show the ranges where a majority of the values lie.

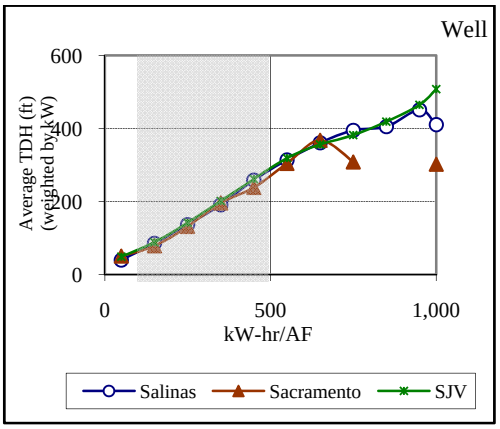
Graph 9: Test distribution.



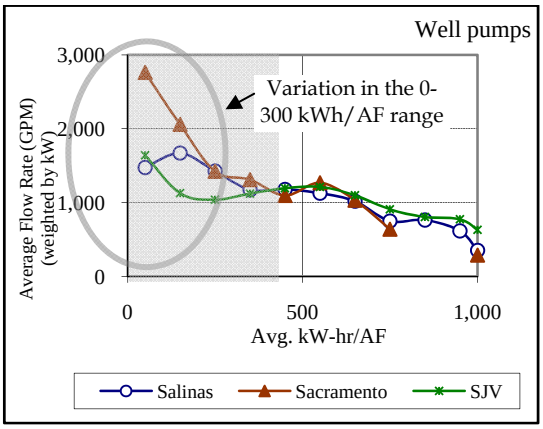
Graph 10: Average input power [kW].



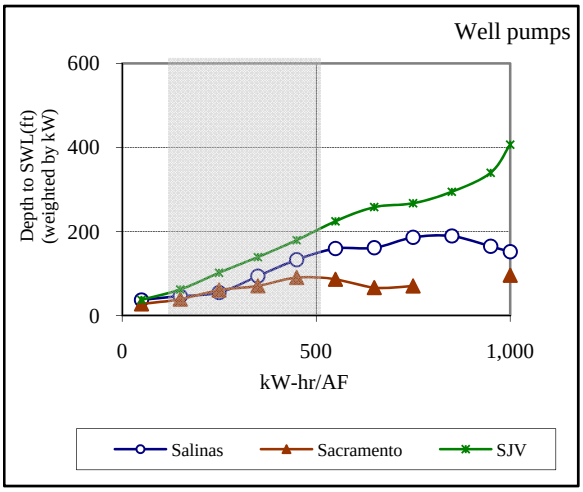
Graph 11: Average total dynamic head (TDH) [ft] (weighted by input power).



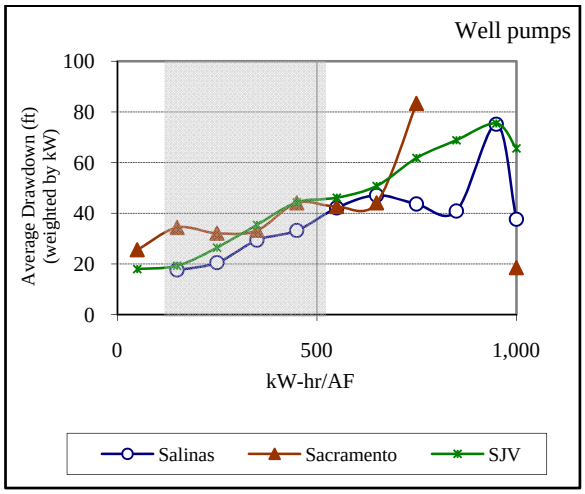
Graph 12: Average flow rate [ft] (weighted by input power).



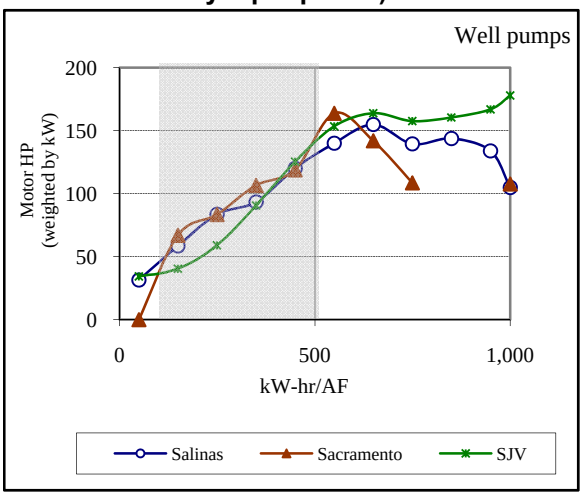
Graph 13: Average depth to standing water level (SWL) [ft] (weighted by input power).



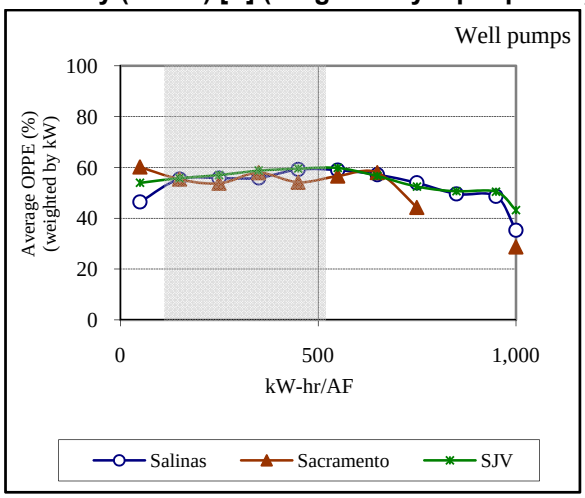
Graph 14: Average drawdown [ft] (weighted by input power).



Graph 15: Average motor HP (weighted by input power).



Graph 16: Average overall pumping plant efficiency (OPPE) [ft] (weighted by input power).



Source: Irrigation Training and Research Center

When comparing the data from the three basins to the kWh/AF, some general observations regarding the well pump data can be made:

1. A majority of the well pump tests fall between 200 and 500 kWh/AF.
2. The Sacramento basin well pump tests differs from the well pump tests in other basins at higher (600+) kWh/AF in all categories. No conclusions are drawn from this data due to the small sample sizes in those ranges.
3. The well pumps tested in the Sacramento and Salinas basins have higher average input power in the 200-500 kWh/AF range than the well pumps in the San Joaquin basin. However, the average input power increases with kWh/ah, and the Salinas and San Joaquin basins have more tests in the higher ranges (400+) than the Sacramento basin. This could explain why the Sacramento and San Joaquin basin-wide averages are nearly equal, and the Salinas basin average is slightly higher.

4. Average regional flow rates vary significantly at low (0-300) kWh/AF, but match well at higher (400+) kWh/AF. Only the Sacramento basin has a significant number of well pump tests in that range (see Graph 9). These low kWh/AF, high flow rate pumps are probably causing the Sacramento basin tests' average flow rate to be so much higher than the test averages in the other basins
5. The San Joaquin basin's well pump tests do not appear to have a significantly greater drawdown than the other basins (see Graph 14). This can be explained mainly by the distribution of tests. The San Joaquin basin has a significant percent of its tests in the 500-800 kWh/AF range (see Graph 9), and the tests in those ranges have higher drawdown values than the 0-500 kWh/AF ranges and the Salinas basin (which also has a significant percent of its tests in the higher range) and input power (what the average drawdown values are weighted by) than in the 0-500 kWh/AF ranges. This could cause the basin's overall higher value, without making the values in the 200-500 range significantly higher in comparison to the other two basins.
6. The average total dynamic head in each kWh/AF range is almost identical for the three basin averages, even though the average total dynamic head of the Sacramento basin well pump tests was lower than the tests other basins. This is probably due to the fact that the majority of the well pump tests in the Sacramento basin had slightly lower kWh/AF than the well pump tests in the other basins; the lower kWh/AF ranges had lower average total dynamic heads for all basins.
7. The average depth to standing water level increases with the kWh/AF, possibly indicating the effect larger pumps are having on their local water tables.

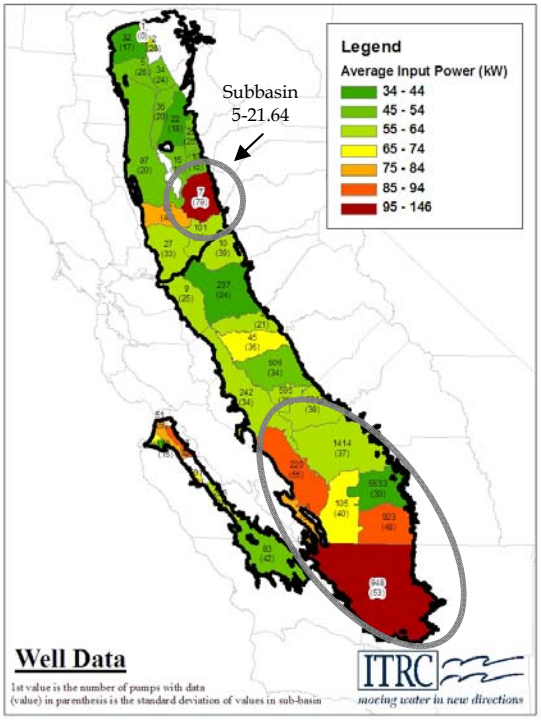
Regional Comparison by Subbasin

Maps were created characterizing the groundwater subbasins according to available pump data. The Central Valley of California can be divided into three basins (Salinas, Sacramento, and San Joaquin Valley), each divided into a number of subbasins to examine the validity of the regional conclusions.

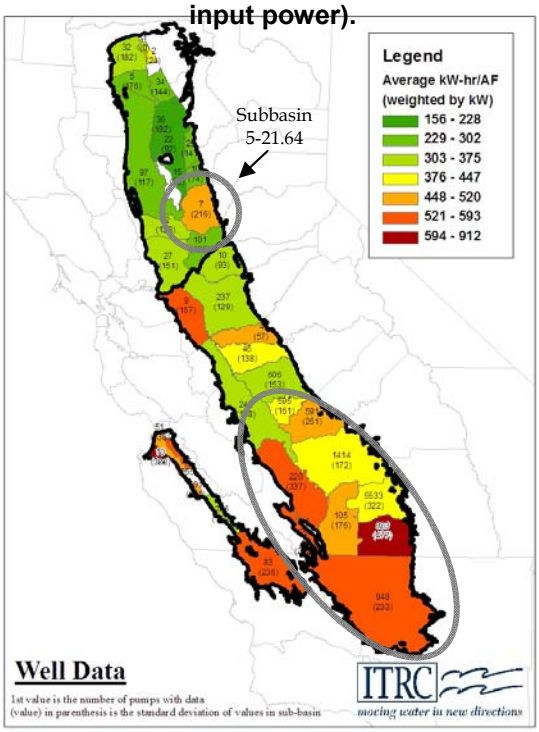
The following maps illustrate the three groundwater basins (and their subbasins) with varying parameters:

- Average Input Power [kW] (Map 1)
- Average kWh/AF (weighted by input power) (Map 2)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power) (Map 3)
- Average Flow Rate [ft] (weighted by input power) (Map 4)
- Average Depth to Standing Water Level (SWL) [ft] (weighted by input power) (Map 5)
- Average Drawdown [ft] (weighted by input power) (Map 6)
- Average Motor HP (weighted by input power) (Map 7)
- Average Overall Pumping Plant Efficiency (OPPE) [%] (weighted by input power) (Map 8)

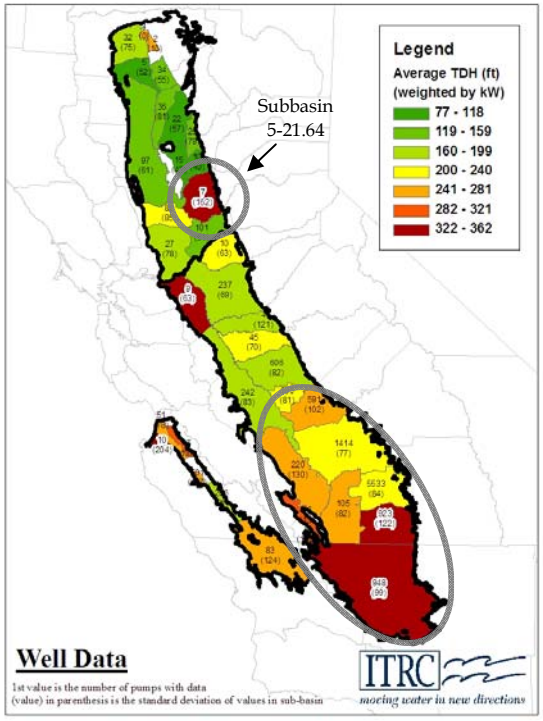
Map 1: Average input power [kW].



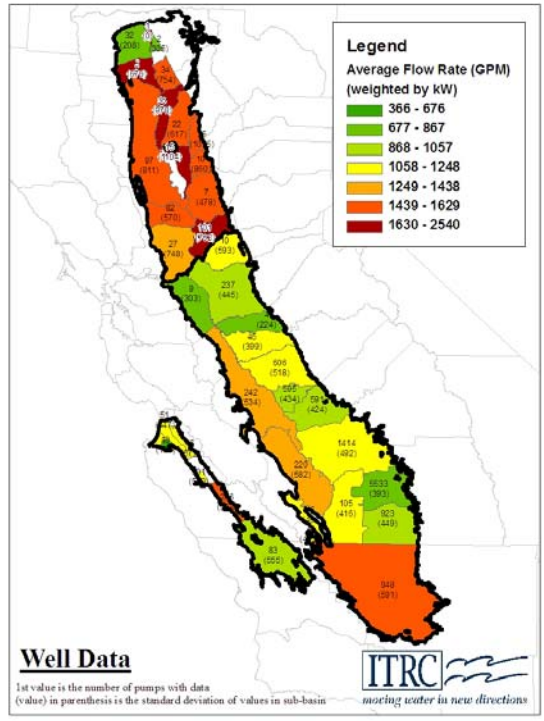
Map 2: Average kWh/AF (weighted by input power).



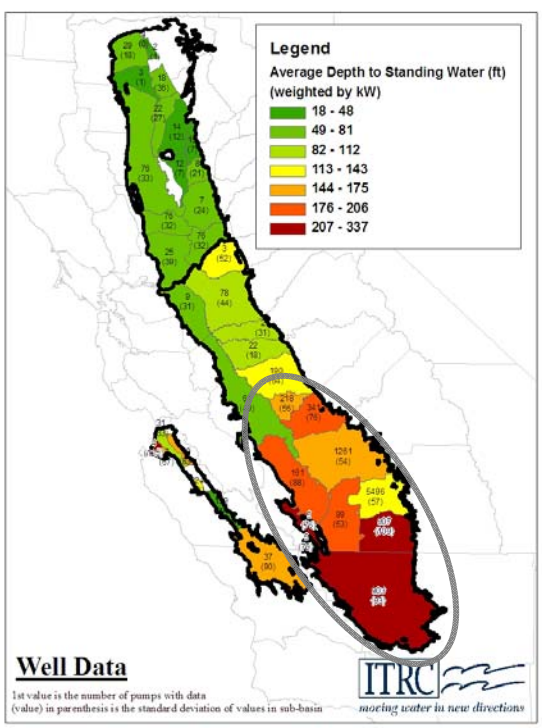
Map 3: Average total dynamic head (TDH) [ft] (weighted by input power).



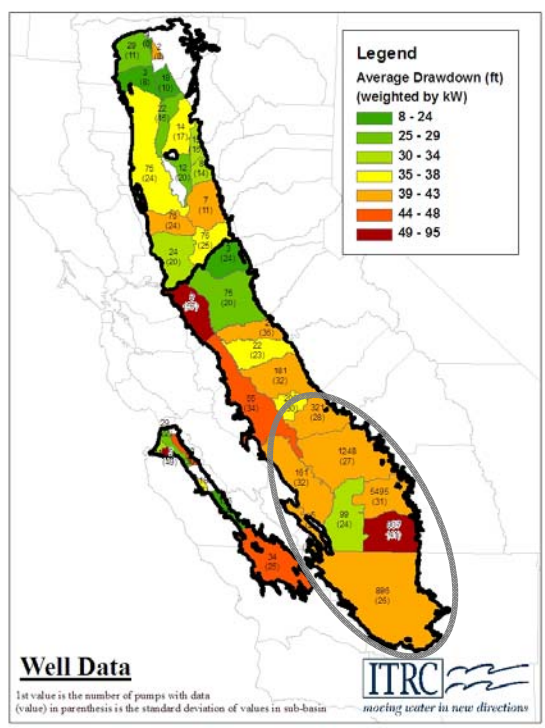
Map 4: Average flow rate [ft] (weighted by input power).



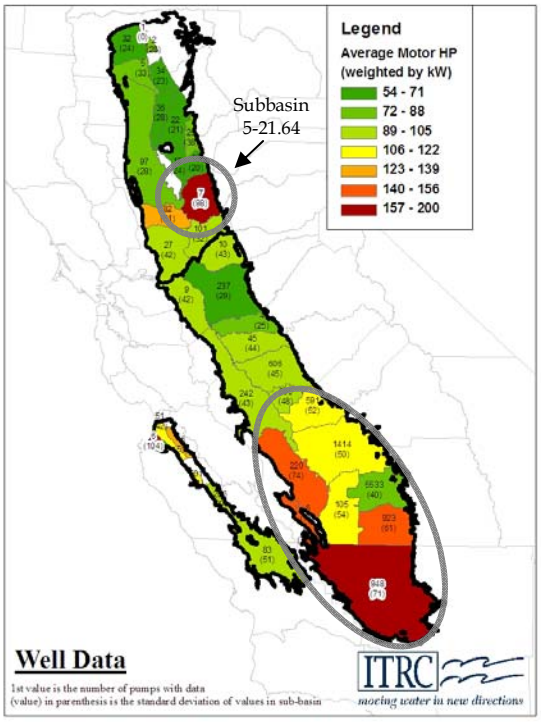
Map 5: Average depth to standing water level (SWL) [ft] (weighted by input power).



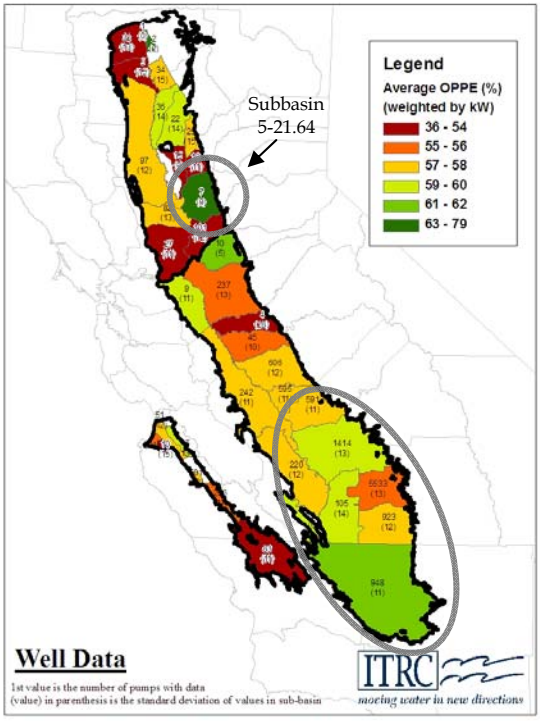
Map 6: Average drawdown [ft] (weighted by input power).



Map 7: Average motor HP (weighted by input power).



Map 8: Average overall pumping plant efficiency (OPPE) [%] (weighted by input power).



Source: Irrigation Training and Research Center

When comparing the data from the three basins by subbasin, some general observations regarding the well pump data can be made:

1. There are clear basin trends for average input power, kWh/AF, total dynamic head, flow rate, depth to standing water, and motor HP (it does not appear that certain sub-basins are heavily skewing the data).
2. The Sacramento basin has one subbasin (5-21.64) that has well pump test values that differ greatly from the rest of the basin. This subbasin has only 7 tests, 3 of which are very large pumps (input power greater than 100 kW, motor HP greater than 100, discharge pressure greater than 100 psi, flow rate greater than 1000 GPM, total dynamic head greater than 375 ft, and kWh/AF greater than 500) with high overall pumping plant efficiencies (greater than 68%).
3. The San Joaquin basin appears to have more extreme well pump test values in the southern portion compared to the northern portion.
4. When comparing the overall pumping plant efficiency (OPPE) (a calculation based on the input power, flow rate, and total dynamic head), the Salinas and Sacramento basins' well pump tests have a slightly lower average OPPE than the San Joaquin basin; however, the majority of subbasin average OPPEs can be contained between 54% and 62%.

Summary of Major Well Pump Testing Regional Conclusions

The major conclusions drawn from the well pump test data include:

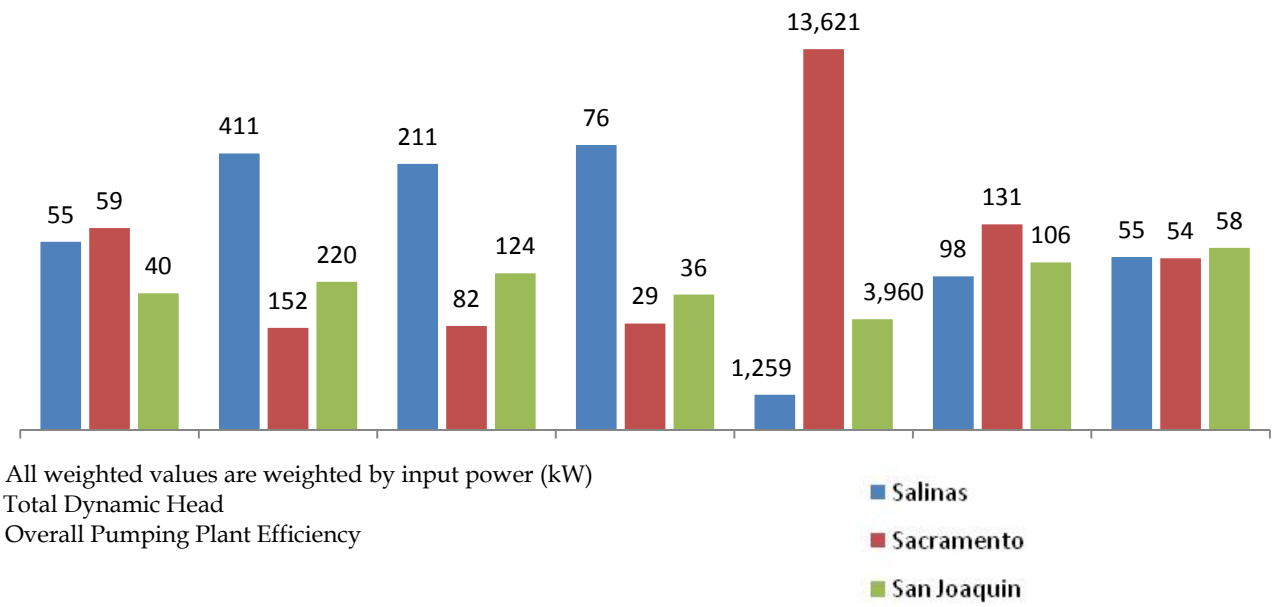
1. All three basins' well pump tests have very similar average weighted overall pumping plant efficiencies (~56%), with the majority of the values contained between 54% and 62%.
2. A majority of the well pump tests fall between 200 and 500 kWh/AF.
3. The basins have trends in data between the Sacramento, Salinas, and San Joaquin basins.
    a. In general, the Salinas basin well pump tests had, in relation to the well pump tests in the other basins:
        i. Slightly higher input power
    b. In general, the Sacramento basin well pump tests had, in relation to the well pump tests in the other basins:
        i. Lower kWh/AF
        ii. Lower total dynamic head
        iii. Higher flow rates
        iv. Lower depths to the standing water level
        v. Slightly lower motor HP
    c. In general, the San Joaquin basin well pump tests had, in relation to the well pump tests in the other basins:
        i. Greater depths to the standing water level
        ii. Higher drawdown
4. The San Joaquin basin's well pump tests had more extreme values in most categories in the southern region as compared to the northern region.
5. The Sacramento basin has one subbasin (5-21.64) that has well pump test values that differ greatly from the rest of the basin. This subbasin has only 7 tests, 3 of which are very large pumps (input power greater than 100 kW, motor HP greater than 100, discharge pressure greater than 100 psi, flow rate greater than 1000 GPM, total dynamic head greater than 375 ft, and kWh/AF greater than 500).
6. The average depth to standing water level varies greatly between basins.
7. Within each basin, the average depth to standing water level increases with the kWh/AF, possibly indicating the effect larger pumps are having on their local water tables.
8. About 7% of the Sacramento basin's well pump tests are low (0-100) kWh/AF, high (>2000) flow well pumps.

Non-Well Pump Subbasin Comparisons

Over the three groundwater basins, 2,874 non-well pump tests were performed. The following table summarizes the averages of a variety of factors from non-well pump tests in each of the three groundwater basins.

Table 37: Summary of regional non-well pump test data.

Average Input Power [kW]	Average Weighted[1] kWh/AF	Average Weighted[1] TDH[2] [ft]	Average Weighted[1] Discharge Pressure [psi]	Average Weighted[1] Flow Rate [GPM]	Average Weighted[1] Motor HP	Average Weighted[1] OPPE[3] [%]



[1] All weighted values are weighted by input power (kW)
[2] Total Dynamic Head
[3] Overall Pumping Plant Efficiency

Source: Irrigation Training and Research Center

When comparing the data from the three basins, some general observations regarding the non-well pump data can be made:

1. All 3 basins' non-well pump tests have similar average overall pumping plant efficiencies (~55%).
2. For almost all other values, the Sacramento and Salinas basins are the two extremes, with San Joaquin in between.
3. The Sacramento basin's non-well pump tests have a much higher average flow rate, slightly higher average motor HP, and lower average kWh/AF, total dynamic head, and discharge pressure than the other basins.
4. The Salinas basin's non-well pump tests have a higher average kWh/AF, total dynamic head, and discharge pressure, and a lower average flow rate than the other basins.
5. The San Joaquin basin's non-well pump tests have lower input power than the other basins.

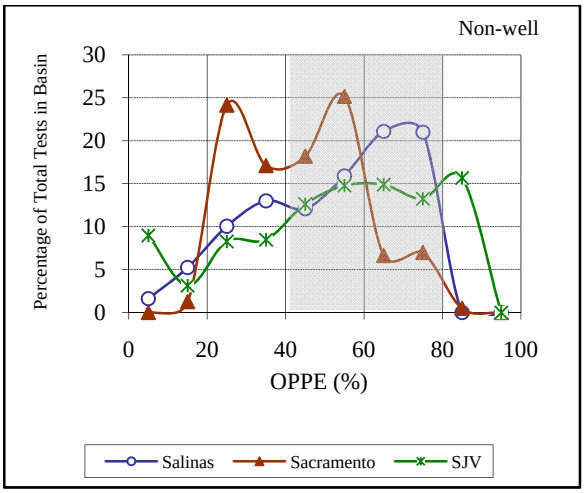
Regional Comparison by Overall Pumping Plant Efficiency (OPPE)

The data for each basin was compared with overall pumping plant efficiency (%) to:

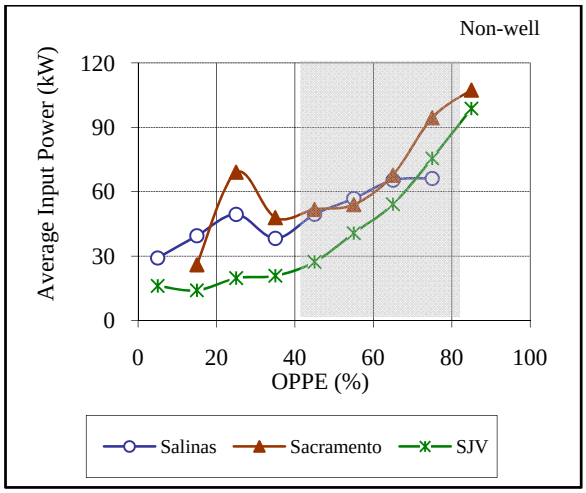
- Test Distribution (Graph 17)
- Average Input Power [kW] (Graph 18)
- Average kWh/AF (weighted by input power) (Graph 19)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power) (Graph 20)
- Average Discharge Pressure [psi] (weighted by input power) (Graph 21)
- Average Flow Rate [ft] (weighted by input power) (Graph 22)
- Average Motor HP (weighted by input power) (Graph 23)

The values are grouped into 10% ranges, with the point at the midpoint of the range (for example, the average value for the 21-30% range is placed at the 25% point). The grayed areas show the ranges where a majority of the values lie.

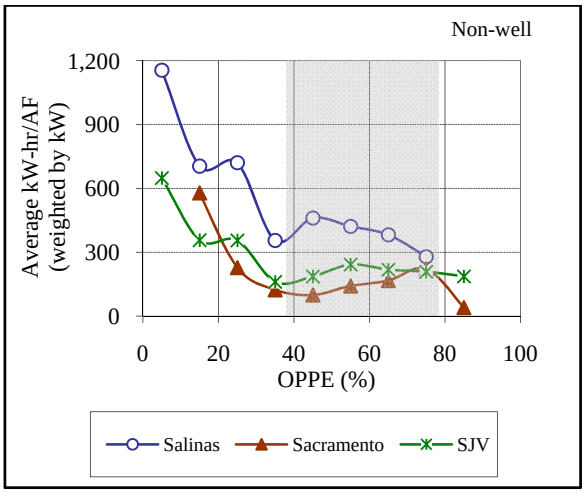
Graph 17: Test distribution.



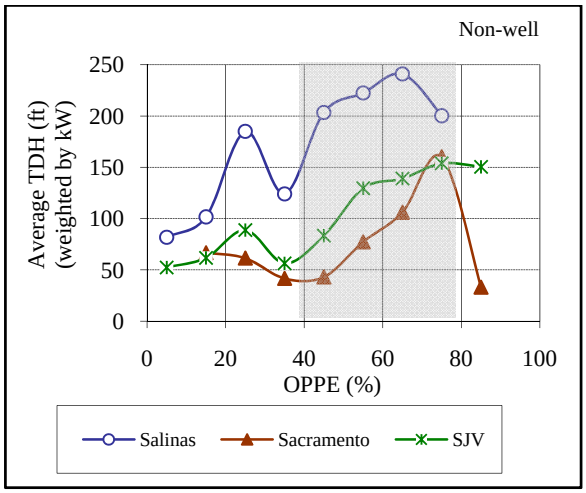
Graph 18: Average input power [kW].



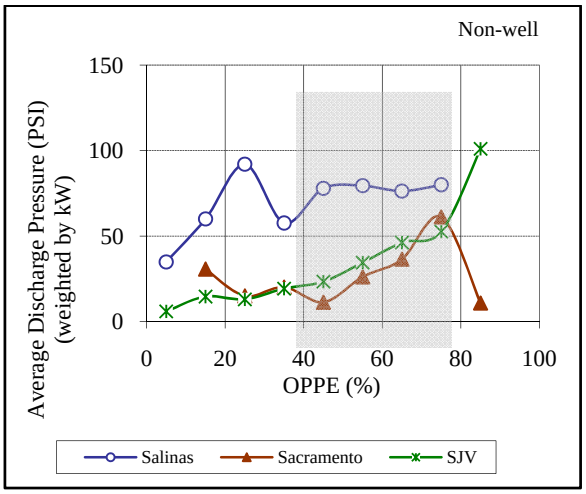
Graph 19: Average kWh/AF (weighted by input power).



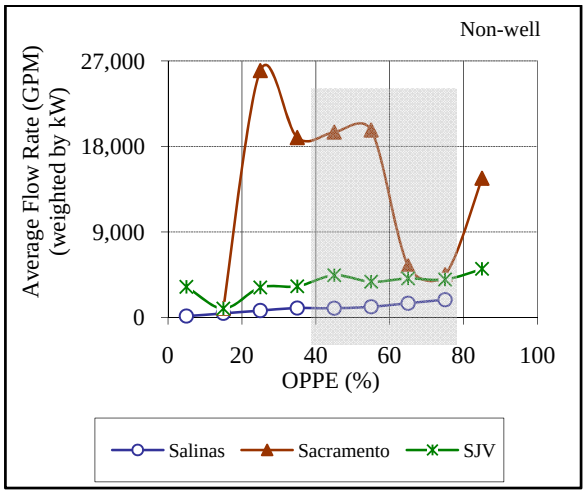
Graph 20: Average total dynamic head (TDH) [ft] (weighted by input power).



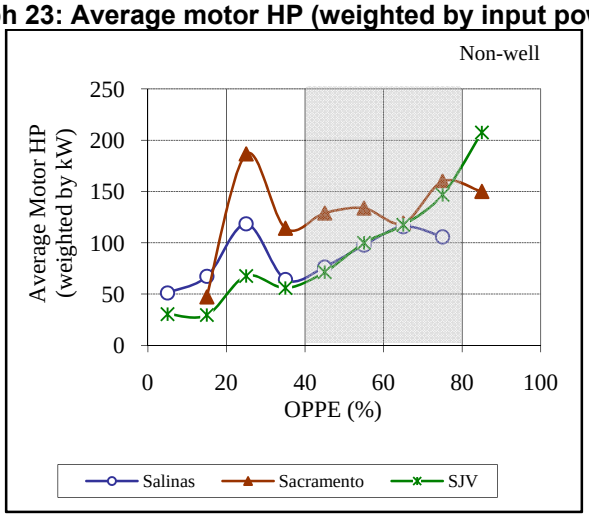
Graph 21: Average discharge pressure [psi] (weighted by input power).



Graph 22: Average flow rate [ft] (weighted by input power).



Graph 23: Average motor HP (weighted by input power).



Source: Irrigation Training and Research Center

When comparing the data from the three basins to the overall pumping plant efficiency (OPPE), some general observations regarding the non-well pump data can be made:

1. A majority of the non-well pump tests fall between the 40-80% OPPE ranges; however, the distributions are very different by basin, and the peak values occur in different ranges (60-70% for Salinas, 50-60% for Sacramento, and 80-90% for San Joaquin).
2. Across nearly all of the OPPE ranges, the Sacramento basin's non-well pump tests have a much higher average flow rate, and a lower average kWh/AF, total dynamic head, and discharge pressure than the non-well pump tests in other basins.
3. Across nearly all of the OPPE ranges, the Salinas basin's non-well pump tests have a higher average kWh/AF, total dynamic head, discharge pressure, and motor HP and a lower average flow rate than the non-well pump tests in other basins.

4. Across nearly all of the OPPE ranges, the San Joaquin basin's non-well pump tests have a lower average input power than the non-well pump tests in other basins.

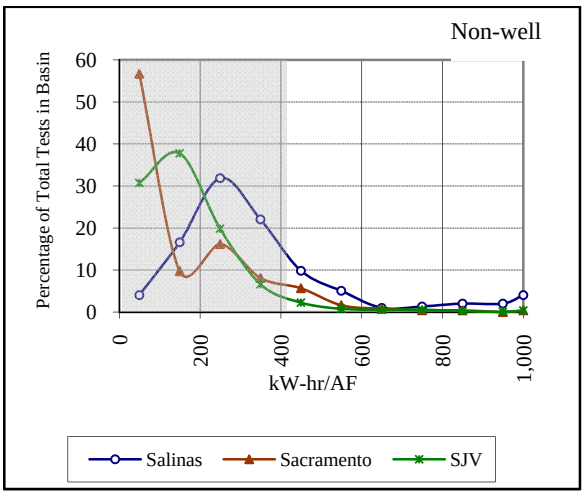
Regional Comparison by Energy Consumption Per Volume Pumped

The data for each basin was compared with kWh/AF to:

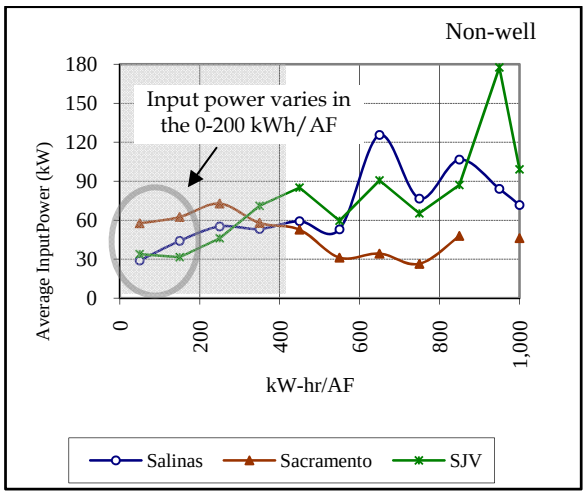
- Test Distribution (Graph 24)
- Average Input Power [kW] (Graph 25)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power) (Graph 26)
- Average Discharge Pressure [psi] (weighted by input power) (Graph 27)
- Average Flow Rate [ft] (weighted by input power) (Graph 28)
- Average Motor HP (weighted by input power) (Graph 29)
- Average Overall Pumping Plant Efficiency (OPPE) [%] (weighted by input power) (Graph 30)

The values are grouped into ranges of 100 kWh/AF with the point at the midpoint of the range (for example, the average value for the 201-300 kWh/AF range is placed at the 250 kWh/AF point). Each basin had a single data point placed at 1000 kWh/AF that represents the y-axis average value for all data points greater than 1,000 kWh/AF. The grayed areas show the ranges where a majority of the values lie.

Graph 24: Test distribution.



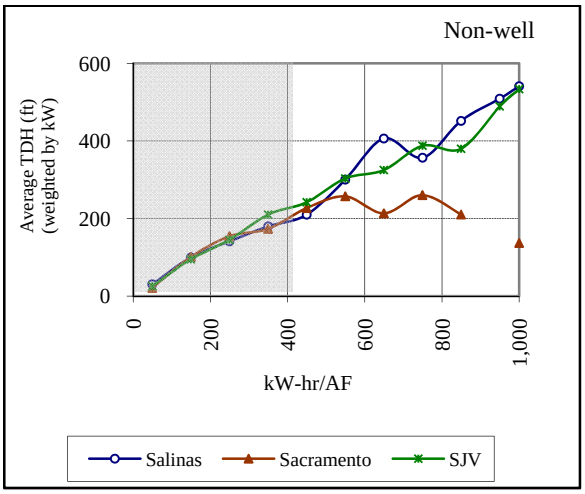
Graph 25: Average input power [kW].



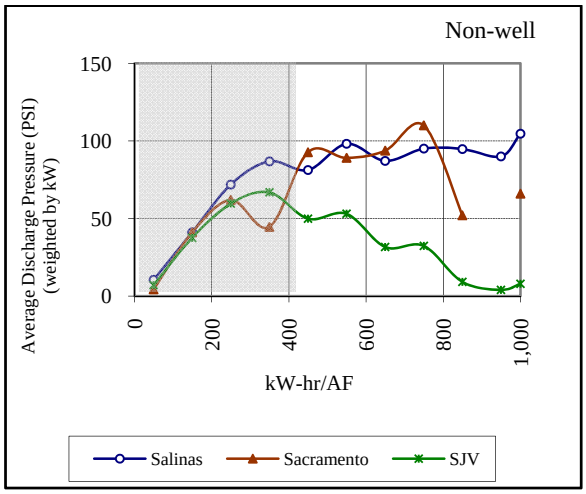
Graph 26. Average total dynamic head (TDH) [ft] (weighted by input power).

Graph 27. Average discharge pressure [psi] (weighted by input power).

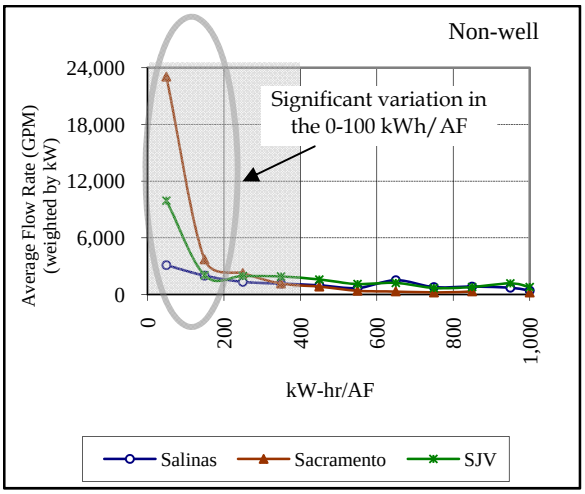
Source: Irrigation Training and Research Center

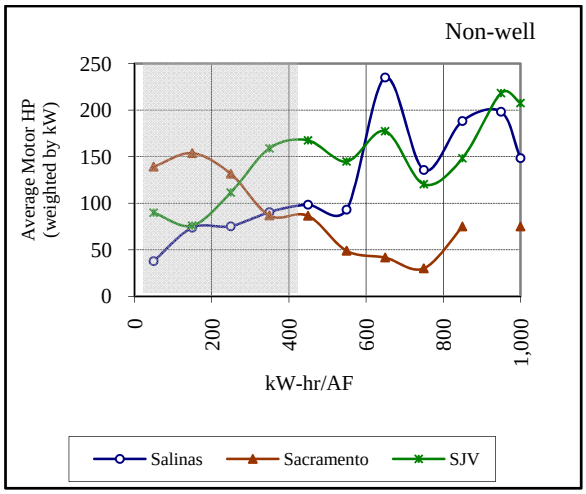


Graph 28: Average flow rate [ft] (weighted by input power).

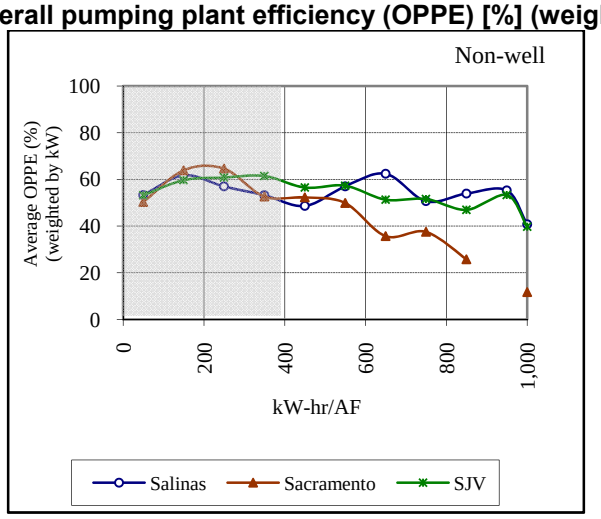


Graph 29: Average motor HP (weighted by input power).





Graph 30: Average overall pumping plant efficiency (OPPE) [%] (weighted by input power).



Source: Irrigation Training and Research Center

When comparing the data from the three basins to the kWh/AF, some general observations regarding the non-well pump data can be made:

1. The peak percent of total tests for each basin occurs in a different range. For the Sacramento basin, the peak is in the 0-100 kWh/AF range; for Salinas, the peak is in the 200-300 kWh/AF range; for San Joaquin, the peak is in the 100-200 kWh/AF range.
2. The Sacramento basin's non-well pump tests differs from the rest at higher (600+) kWh/AF in all categories. No conclusions are drawn from this data due to the small sample sizes in those ranges.
3. There is a large variation in basin non-well pump test values for the input power and average weighted flow rate in the 0-200 kWh/AF range (where a significant portion of the Sacramento and San Joaquin basin tests occurred).

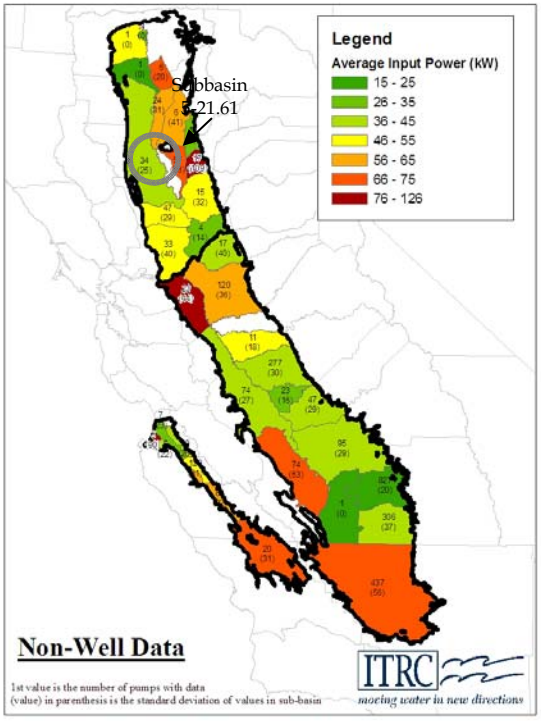
Regional Comparison by Subbasin

Maps were created characterizing the groundwater subbasins according to available pump data. The Central Valley of California can be divided into three basins (Salinas, Sacramento, and San Joaquin Valley), each divided into a number of subbasins to examine the validity of the regional conclusions.

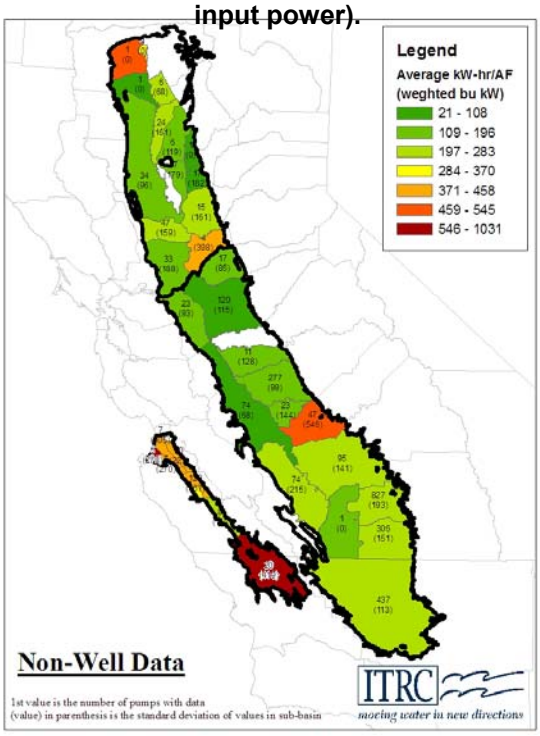
The following maps illustrate the three groundwater basins (and their subbasins) with varying parameters:

- Average Input Power [kW] (Map 9)
- Average kWh/AF (weighted by input power) (Map 10)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power) (Map 11)
- Average Discharge Pressure [psi] (weighted by input power) (Map 12)
- Average Flow Rate [ft] (weighted by input power) (Map 13)
- Average Motor HP (weighted by input power) (Map 14)
- Average Overall Pumping Plant Efficiency (OPPE) [%] (weighted by input power) (Map 15)

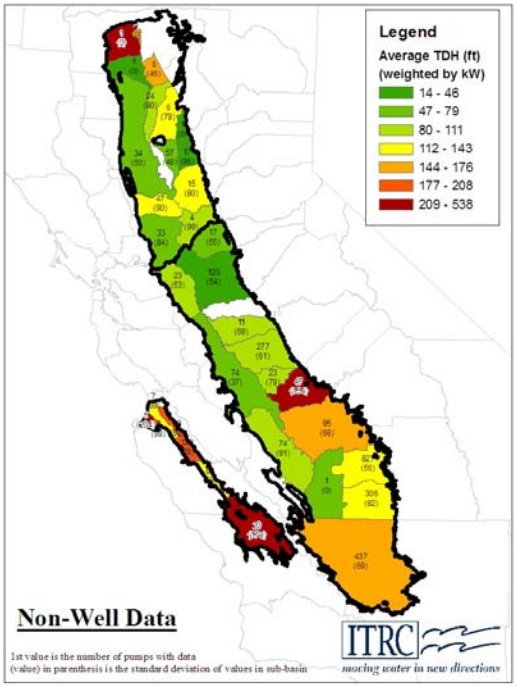
Map 9: Average input power [kW].



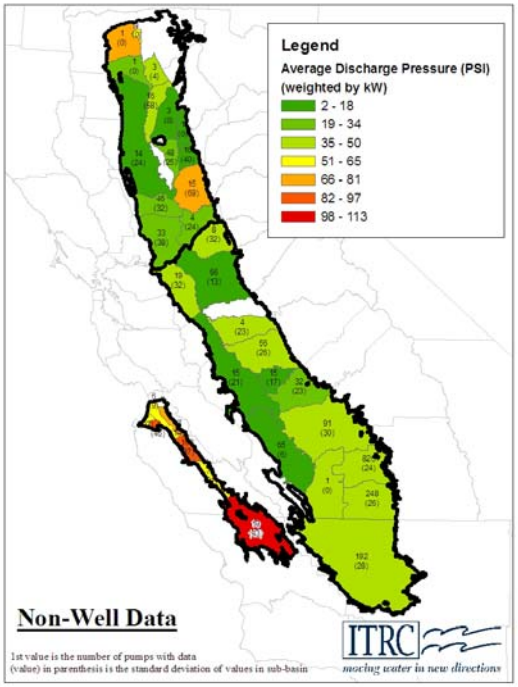
Map 10: Average kWh/AF (weighted by input power).



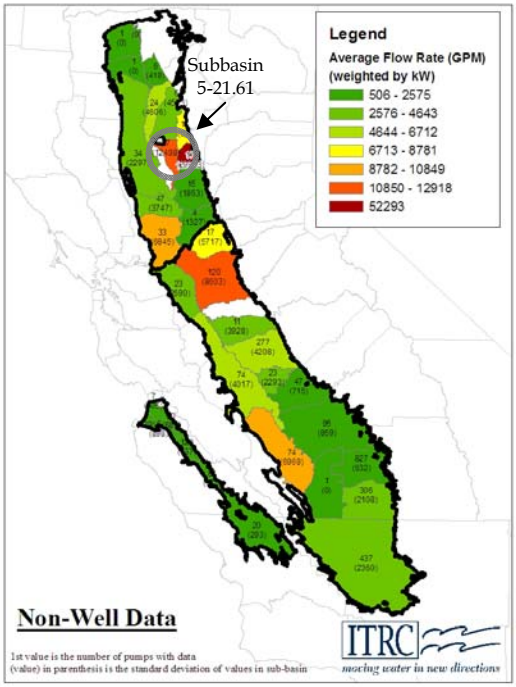
Map 11: Average total dynamic head (TDH) [ft] (weighted by input power).



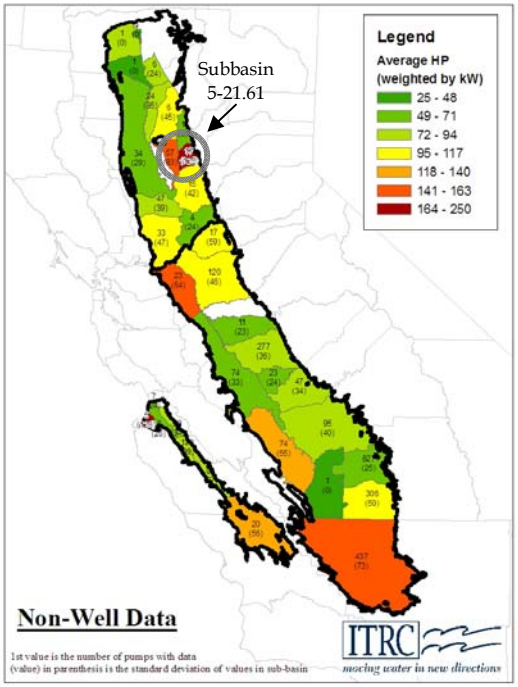
Map 12: Average discharge pressure [psi] (weighted by input power).



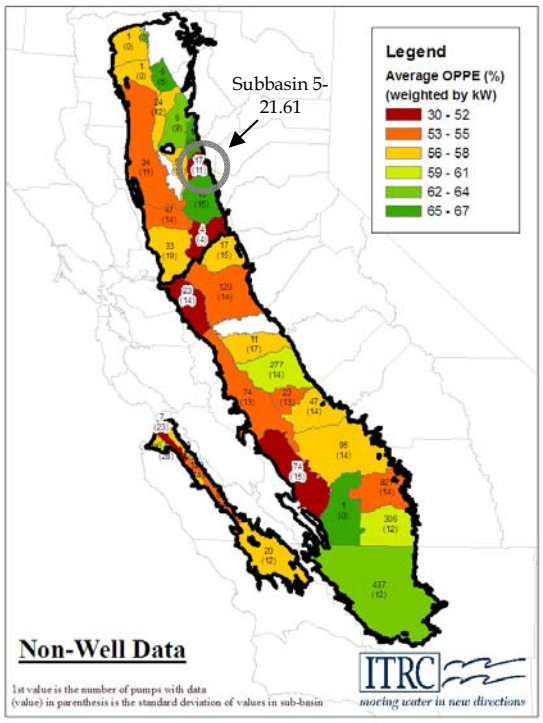
Map 13: Average flow rate [ft] (weighted by input power).



Map 14: Average motor HP (weighted by input power).



Map 15: Average overall pumping plant efficiency (OPPE) [%] (weighted by input power).



Source: Irrigation Training and Research Center

When comparing the data from the three basins by subbasin, some general observations regarding the non-well pump flow rate data can be made:

1. The Sacramento and San Joaquin basins' non-well pump tests do not have basin-wide trends like the basins' well pump tests appeared to have. The basins seem to have a range of values, without any clear regional trends. Subbasins with extreme values appear to weight the basin's average values.
2. The Sacramento basin has one subbasin (5-21.61) that has non-well pump test values that differ greatly from the rest of the basin. This subbasin has 17 tests, 8 of which are very large, high flow/low head pumps (input power greater than 150 kW, motor HP greater than 250, discharge pressure less than 10 psi, flow rate greater than 40,000 GPM, total dynamic head less than 10 ft, and kWh/AF less than 30) with low overall pumping plant efficiencies (28-52%).
3. The Salinas basin appears to have the following basin-wide trends: high average total dynamic head, discharge pressure, and kWh/AF, and low average flow rate. This trend could be attributed to the relatively small size of the basin.

Summary of Major Non-Well Pump Testing Regional Conclusions

The major conclusions drawn from the non-well pump test data include:

1. All three basins' non-well pump tests have very similar average weighted overall pumping plant efficiencies (OPPE) (~55%), and a majority of the subbasin average OPPEs can be contained between 53% and 67%. However, the distributions are very different by basin, and the peak OPPE values occur in different ranges (60-70% for Salinas, 50-60% for Sacramento, and 80-90% for San Joaquin).

2. The kWh/AF range with the peak percent of total non-well pump tests for each basin occurs in a different range. For the Sacramento basin, the peak is in the 0-100 kWh/AF range; for Salinas, the peak is in the 200-300 kWh/AF range; for San Joaquin, the peak is in the 100-200 kWh/AF range.

3. The Sacramento and San Joaquin basins' non-well pump tests do not appear to have basin-wide trends like the basins' well pump tests appear to have. The basins seem to have a range of values, without any clear regional trends. Subbasins with extreme values appear to weight some of the basins' average values.

4. The Sacramento basin has one subbasin (5-21.61) that has non-well pump test values that differ greatly from the rest of the basin. This subbasin has 17 tests, 8 of which are very large, high flow- low head pumps (input power greater than 150 kW, motor HP greater than 250, discharge pressure less than 10 psi, flow rate greater than 40,000 GPM, total dynamic head less than 10 ft, and kWh/AF less than 30) with low overall pumping plant efficiencies (28-52%). These tests contribute to the differences found in the overall basin averages.

5. The Salinas basin's non-well pump tests appear to have the following basin-wide trends:
    a. Higher average total dynamic head
    b. Higher discharge pressure
    c. Higher kWh/AF
    d. Lower average flow rate

    This is relative to the non-well pump tests in the other basins. This trend could possibly be attributed to the relatively small size of the basin (less sub-basins to be in same range).

TASK 4.0. PREPARE AND ADMINISTER RD&D COMPETITIVE SOLICITATION

This task was eliminated for a variety of reasons, including:

1. Uncertainty regarding the contracting mechanism.
2. No response from researchers who were contacted by ITRC.
3. No positive response from manufacturers who were contacted by ITRC.

Manufacturers felt that unless a development project was a high company priority for marketing reasons, they could not afford to spend time on it. The ideas such as reducing pressure loss in pressure compensating emitters, lower losses through pressure regulators, and others, were not high on their list of priorities.

TASK 5.0. TECHNOLOGY TRANSFER

The following technology transfer has already occurred:

1. Sand media filter testing.
    a. The report is on the ITRC web page.
    b. The California Agricultural Irrigation Dealers met at Cal Poly and viewed the research and results in the Fall 2010.
    c. Periodic reports have been made to the drip/micro commodity group of The Irrigation Association.
2. Pump component characterization.
    a. The paper "Improving Pump Performance" was presented at the Irrigation Association Technical Conference in Anaheim, CA in November 2008. Authors were Burt, Gaudi, and Howes.
    b. A draft paper on irrigation pumping characteristics in California has been prepared for publication in the Irrigation and Drainage Journal of ASCE.
3. Discussions with SCE and PG&E.
    a. Agricultural irrigation pumping specialists in the main offices of SCE and PG&E have been kept abreast of work and draft reports.
    b. SCE has moved forward with ITRC to develop demonstrations of the importance of proper inlet conditions for pumps, and sand wear and material selection on vertical pumps.
4. GIS-Based Irrigation District Flow Routing/Scheduling.
    a. Many components of the project have already been incorporated into Imperial Irrigation District's water routing programs. Imperial Irrigation District will incorporate more concepts as it moves into its work on implementing the Quantifiable Settlement Agreement.
5. Other reports.
    a. Once the final report is approved by PIER, sections of the report will be re-organized and placed on the ITRC web site.

Once the final report is approved by PIER, several professional papers will be developed and presented at professional conferences.

APPENDIX 1:
Irrigation District Electricity Status, Needs, and Suggestions Survey

August 6, 2007

by
Irrigation Training and Research Center
Cal Poly, San Luis Obispo
805-756-2379

on behalf of
California Energy Commission's
Public Interest Energy Research (PIER)

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Date of Visit	
Cal Poly ITRC staff person:	
Irrigation District	
Contact Information	
Person	
Title	
Phone number	
e-mail, if available	
Address 1	
Address 2	
City	
Zip Code	

The primary purpose of this survey is to identify research, assistance, and policy needs related to electrical energy usage by irrigation districts.

Therefore, we are looking for 3 things from each participating district:

1. Ideas on research, assistance (grants), and policy changes.
2. An understanding of what the present pumping situation is.
3. An understanding of what direction the pumping programs will move.

District Ideas on Research, Grants, and Policy Changes

What are your ideas on the needs for the following, related to specific topics?

Topics	Research	Grants/Low-Interest Loans	Policies
Time-of-Use (peak load)			
Improving efficiency			
Reducing total kWh			
Saving money			
Other (describe)			
Other (describe)			
Other (describe)			

Present Status

	Deep Well Pumps	Drainage Well Pumps	Surface Supply/Booster Pumps	Surface Drain Pumps
Number of pumps				
Number of pumps that have their efficiency checked per year				
Total HP in each category				
Total kWh in each category				
Avg. Pumping Plant Eff., %				
Years of age (# of Pumps)				
0-5 years old				
6 to 25 years old				
26+ years old				
# of pumps rebuilt/yr				
# of Premium motors				
# of VFDs				
# remotely monitored				
# of automatic				
# of remote manual on/off				
# of engines				
Typical voltages				
Typical type of motor				

Present Status (continued)

What is the typical annual maintenance program?	
What is the major reason for rebuilding or repairing pumps?	
Does the district have a power management program?	
What percentage of the total grower turnouts today could go to time-of-use rates if they wanted? (whether they use booster pumps or not)	
Power cost, $/kWh	
Power cost, standby $/kW (and demand charge $/kW if different)	
Does the district belong to a Joint Power Authority? If Yes,	
- Name and other members - What is the benefit? - What kinds of assistance does the authority need and challenges does it face?	

When thinking about pumps, what are the biggest:

Day-to-day challenges?	
Future challenges?	

Future. Plans for the next 5 years.
How many pumps does the district plan to apply the following to?

	Deep Well Pumps	Drainage Well Pumps	Surface Supply/booster Pumps	Surface Drain Pumps
Power Factor Improvement				
VFDs (new)				
Well Cleaning/Maintenance				
Power Monitoring (real-time)				
Automation				
Remote Manual on/off				
Remote Monitoring				
Conversion to Engines				
Estimated Change in Future Usage				
How much more or less kW in the next 5-10 years in each category?				
Why?				
How much more or less kWh in the next 5-10 years in each category?				
Why?				
Are there any plans that include working with some type of district/farmer program to enable farmers to use time-of-use?				

What do you think will happen to power in the future?

	0-5 yrs	6-10 yrs	11-15 yrs
Cost, $/kw-hr			
Standby $/kw			
# of brownouts/yr			
Other restrictions			

Past
What things has the district done with electricity or power recently to improve things?

Previous 0-5 yrs	
Previous 6-10 yrs	
Previous 11-15 yrs	
Have those things been successful?	

APPENDIX 2A:
User's Manual (Sept. 2009)
Water Coordinator DSS

DRAFT
WATER COORDINATOR DECISION SUPPORT SYSTEM SOFTWARE DOCUMENTATION AND USER'S MANUAL

Prepared for:
Imperial Irrigation District

Prepared by:
Brian Westfall
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78 East Center
Logan, Utah 84321

September 3, 2009

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INTRODUCTION

Purpose and Background

This document describes the operation of the Water Coordinator Decision Support System (WCDSS) and includes a tutorial on using WCDSS to carry-over orders. WCDSS is a software tool designed to help the Imperial Irrigation District (IID) Water Coordinators (WCs) determine what water orders should be carried over. In this context, carry-overs are defined as water orders that could not be delivered on the requested date for reasons such as water unavailability, canal capacity problems, or other system limitations or outages. Carry-overs are currently entered into the TruePoint Solutions (TPS) water order and billing system using TrueCanal after the WC has manually calculated canal capacity and made some decisions related to allocating the water supply where demand exceeds supply.

The major advantage of using WCDSS for carry-overs is that it provides an estimated flow at each field delivery gate with a running order based on the scheduled orders in the system. WCDSS flags orders in canal reaches that have a capacity violation under the current order line up. This eliminates the need for manual calculation of canal flow rates. A planned future enhancement of this system will also rank or prioritize each new water order relative to other new water orders based on a rule set that can be selected by the user. The water order rank can then be used to help the WC determine which orders to carry over.

WCDSS will be installed by the IID IT Department. Appendix A contains pertinent installation and maintenance information, and Appendix B contains information on WCDSS system settings. The information in the appendices is targeted primarily for IT personnel use.

Conventions

The different styles shown below have been used in this document to help describe the operation of the WCDSS software.

- References to a particular location of the user interface are in an italics font and look like this: *Ribbon Bar*.
- References to a particular key on the keyboard will be in all-caps, bold, and italics font and look like this: ***ENTER***.
- References to a software button will be in a blue, bold, italics font and look like this: ***Save***.
- References to another section of this document are underlined and in a bold font and will look like this: **Conventions**.

Software Design and Operation Requirements

WCDSS is a Microsoft Windows® application that uses the latest Microsoft .NET Framework technology. It is installed per user and is deployed via the Internet as are any software updates. Each computer running WCDSS requires SQL Server 2005 Express Edition (free from Microsoft), which is the local database server. Also required are version 3.5 (SP1) of the .NET Framework and a free open-source GIS component called Map Window.

Water orders will continue to be entered into the TPS system, as usual, by the WCs or Zanjeros. WCDSS automatically retrieves current orders from the TPS database server and saves the needed information to the local database through a process called transactional replication. When WCDSS runs, it automatically triggers the local installation of SQL Server Express to retrieve any new or changed orders from the TPS database. A reliable network connection to the database server is imperative for WCDSS operation. Once the orders have been retrieved and stored locally, all processing is done on the WC's computer. Note that WCDSS can be updated with new TPS order data at anytime by clicking the ***Refresh Orders*** button.

Once orders are marked for carry-over, they must be committed back to the TPS database server. This is done by clicking the ***Update TP*** button. This triggers the same web service calls that TrueCanal uses, thereby ensuring that carry-overs are handled identically whether initiated in TrueCanal or WCDSS.

USING WCDSS

Getting Started

Running WCDSS

To start WCDSS locate the WCDSS folder under the Windows Start menu. Expand the folder and double-click on "WCDSS". WCDSS may start immediately or it may request permission to download an update if one is available (Figure 1). If this is the case, click the "OK" button to proceed with the download. It is always recommended to allow an update to occur when prompted.

When WCDSS initially starts running, it triggers the process of retrieving and saving the latest water-order data to the local database. Depending on the number of records retrieved, this process may take one to two minutes, depending on the connection speed. During this process, a message will be displayed in the center of the WCDSS screen stating that WCDSS is "Connecting to the TruePoint database server and retrieving water order data" (Figure 2). Upon successful record retrieval, the message disappears. If the connection fails for any reason, the panel will turn red and display an error message (Figure 3). If this occurs, the IT department should be contacted to resolve any connectivity problems.

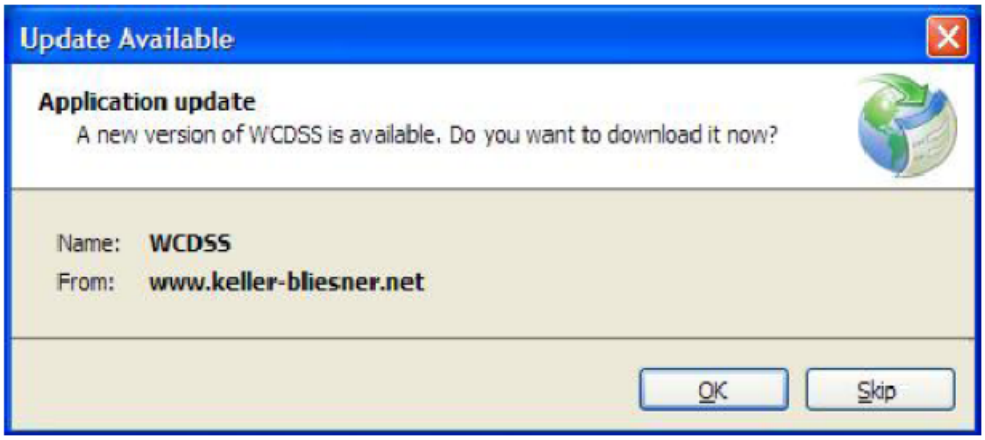


Figure 1. Update request dialog box.

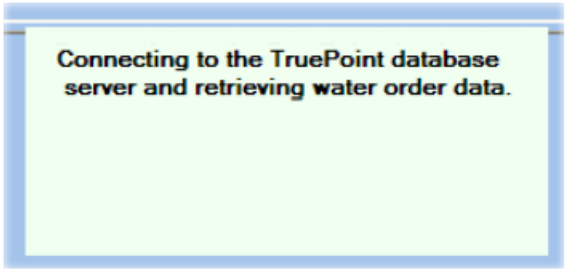


Figure 2. WCDSS database connection status panel.

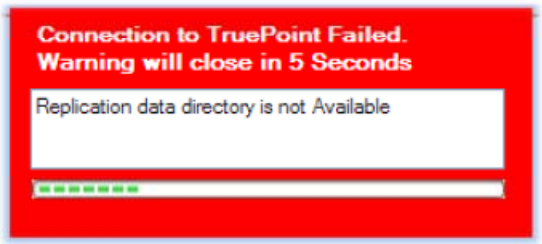


Figure 3. WCDSS database connection failure message.

Once the user-interface screen opens, ensure that you are in the *Water Order* tab/window available in the *Ribbon Bar* (Figure 4). Next, using the available drop-down menus, select the proper *Division* and *Area* in the two fields located in the top-left corner of the screen (Figure 4). Once this is completed, the corresponding zanjero runs will be displayed with the corresponding laterals in the *Canal Hierarchy Tree*. It may take several seconds between the selection of the *Area* and the population of the *Canal Hierarchy Tree*. This delay occurs because all required water-order information is being loaded into memory, which decreases the lag involved in subsequent program operations.

For demonstration purposes, the Orchid run (shown as *ORC* on screen) has been selected in the *Canal Hierarchy Tree* in Figure 4, and all active orders for the Orchid run are displayed in the *Orders Grid*. The *Canal Hierarchy Tree* contains four other data columns besides the run/lateral (*Run/Lat)* column. The *Dem* column shows the demand in cfs (cubic feet per second) for the selected run or lateral. The demand of 24 cfs is the sum of the *Order cfs* column in the *Orders Grid*. If the Olive run (*OLI*) had been selected, only the orders for the Olive run would be displayed.

The summary for each of the laterals on the run is shown in the *Run Summary Grid*. The content of the *Demand Statistics Grid* varies somewhat, depending on the selection in the *Canal Hierarchy Tree*. The *Demand Statistics Grid* columns are described in order from left to right (Figure 4) as follows:

- Allotted. The total cfs allotted to the selected area.
- Dem. The total cfs demand for the selected area
- Variance. The difference between the allotted and the demand. If the variance is negative, the orders are typically carried over until a near zero variance is reached.

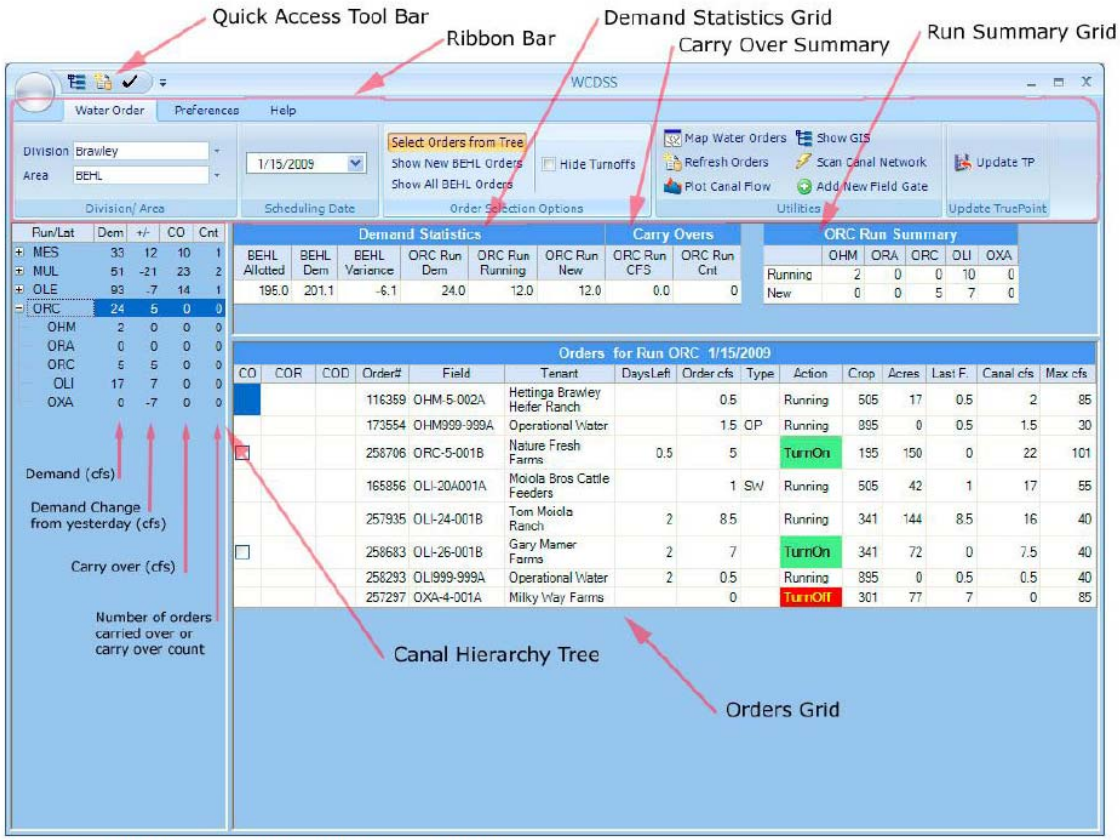


Figure 4. WCDSS user interface with features labeled.

The next 5 columns are dependent on the selection in the *Canal Hierarchy Tree*. In Figure 4, the Orchid run was selected so the total Orchid demand, running orders, new orders and carry over cfs and order count are displayed. If a single lateral had been selected, these statistics would reflect the status of the selected lateral.

Ribbon Bar

The *Ribbon Bar* (Figure 4) shows three tabs. The *Water Order* tab is selected in Figure 4. Each tab presents a variety of controls, which are outlined below:

- *Water Order* Tab

  a. Division Brawley This field allows you to select one of the five IID divisions.

  b. Area BEHL This field allows you to select an area depending on the selected division.

  c. 1/25/2009 Activate this control by clicking the arrow, which will display a calendar that permits selection of the schedule date.

  d. Select Orders from Tree If this button is selected, then the *Orders Grid* is populated based on the *Canal Hierarchy Tree* selection.

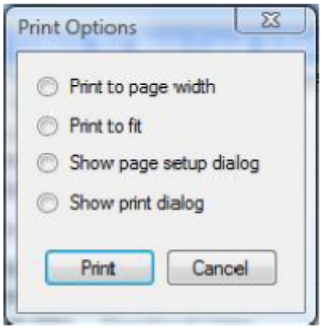
  e. Show New BEHL Orders If this button is selected, then only new orders are displayed. These are orders with a *TurnOn* flag (black text on a green background) in the *Action* column of the *Orders Grid*. The button label changes depending on the Area selection.

  f. Show All BEHL Orders If this button is selected, then all current orders are displayed. The button label changes depending on the area selection.

  g. Hide Turnoffs If this button is checked, the orders with a *TurnOff* flag (yellow text on a red background) are not displayed in the *Orders Grid*.

  h. Print Orders If this button is selected, the print options dialog is displayed in preparation to print the water order details as shown in the main water order grid. The short cut key is the "Control + p" key combination.

     - Print to page width. The printed text is sized to the width of the page.
     - Print to fit. Fits the data on a single page.
     - Displays a page setup dialog that allows setting paper size, page orientation and margins.
     - Shows the standard print dialog. Allows access to printer options.



i. To Excel Allows the order details to be saved to an Excel file. When this button is selected, the "Save As" file dialog opens. Enter a file name select the save button. The file will be saved to the hard drive and opened in Excel automatically. Excel must be installed for the file to open automatically. The short cut key is the "Control + e" key combination.

j. Map Water Orders All orders, excluding turnoffs, are displayed using Google Maps. Markers on the map are selectable and display order information (Figure 5).

k. Refresh Orders Clicking this button retrieves the latest orders from the TPS database. Refer to the **Refresh Orders** section of this manual for further instructions in regards to this function.

l. Plot Canal Flow If an order is selected in the *Orders Grid*, then clicking this button will open a window that shows a plot of the canal flow at upstream delivery gates based on the area orders (Figure 6). It also shows a plot of canal capacity. This is a tool used for locating reach capacity problems. It is important to note that once you move upstream into a canal reach that has water to be delivered to another area, the flow calculation will not be accurate.

m. Show GIS Clicking this button will open a new window and show the WCDSS GIS. Refer to the **WCDSS GIS** section of this manual for further instructions in regards to this function.

n. Scan Canal Network Clicking this button initiates a scan of the canal network; this utility looks for upstream reach restrictions. This step is typically only required when a new gate is added. See the **Add New Field Delivery Gate** section of this manual for further instructions in regards to this process.

o. Add New Field Gate Clicking this button initiates the utility for adding a new field delivery gate. See the **Add New Field Delivery Gate** section of this manual for further instructions in regards to this process.

p. Update TP Clicking this button commits or uploads water orders selected for carry-over back to TruePoint.

- Preferences Tab

a. Image Path D:\Work\IID\GIS\IID_2ft_mo: This field allows you to enter a file path to the GIS background image. See the **WCDSS GIS** section of this manual for further instructions in regards to this function.

b. ☑ Display image as GIS background If this field is checked, then the selected image is displayed as the GIS background image. If it is unchecked, then no background image is displayed.

c. Settings Clicking this button opens the WCDSS program settings. See **Appendix B** for further instructions regarding program settings.

- Help Tab

a. About WCDSS Clicking this button displays a splash screen that shows the software version and date information.

b. Check for Updates Clicking this button will initiate a search for any WCDSS updates published on the Keller-Bliesner Engineering web site. If available, you will then be prompted to install these updates.

c. Online Help Clicking this button will open a help file in .PDF format.

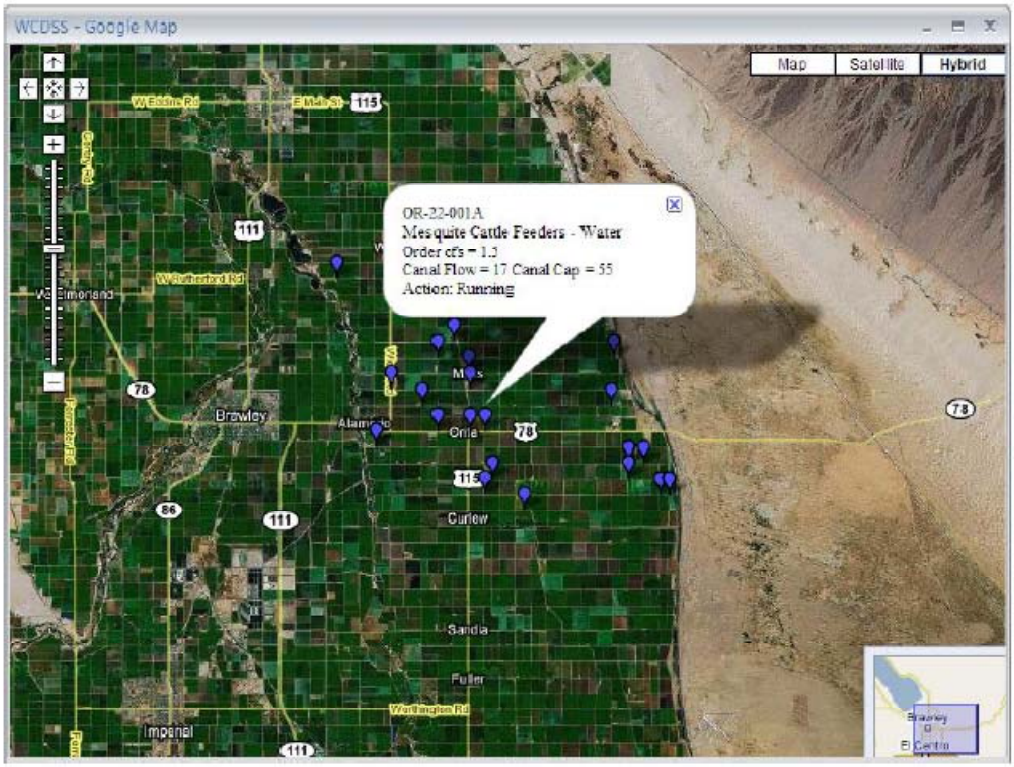


Figure 5. Mapping of orders using Google Map.

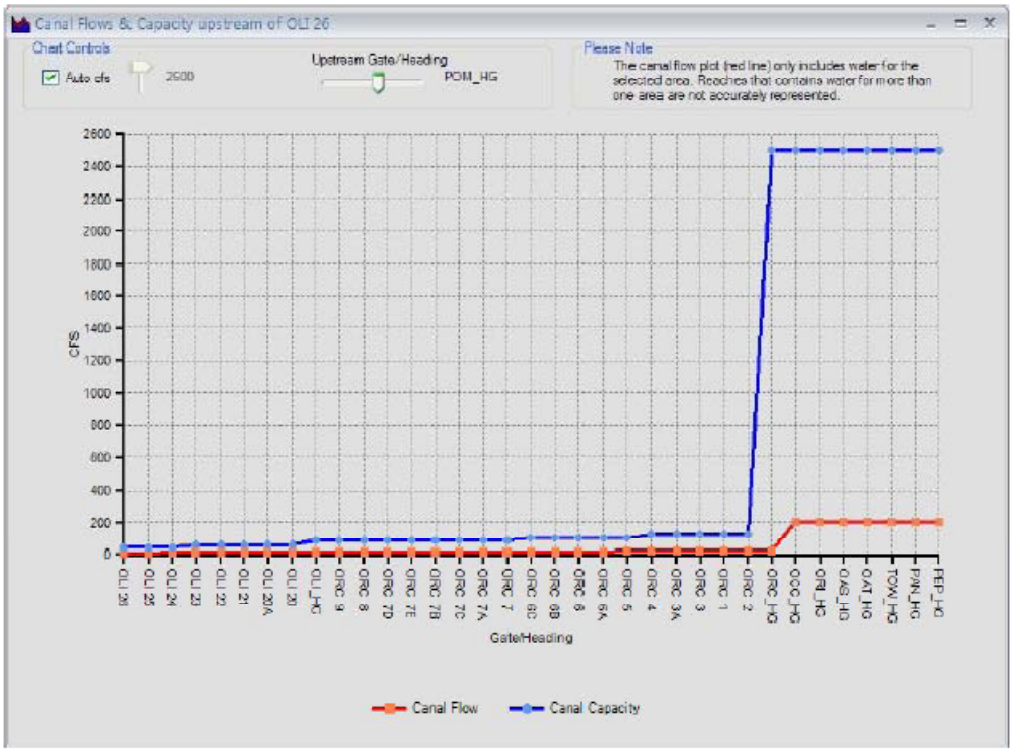


Figure 6. Canal flow/capacity utility plot.

Carrying Over Water Orders

For the purposes of instruction, we have used the Brawley Division and the BEHL sales area from July 14, 2008, as an example scenario in order to demonstrate how to use WCDSS to carry over water orders (Figure 7). In the screen capture in Figure 7, the *Orders Grid* shows orders for the currently selected Orchid lateral. Several orders in the *Orders CFS* column are highlighted in yellow by WCDSS, which indicates a canal capacity violation.

For example, the current order line up requires a flow of 110 cfs (*Canal cfs* column) at ORC-6, and the 14-cfs order for ORC-6 is included in this 110 cfs value. Because the maximum capacity of the canal reach where ORC-6 is located is 101 cfs (*Max cfs* column), the order is flagged in yellow to indicate that this order is exceeding canal capacity. In addition, the *BEHL Variance* (-56.7 cfs) is the difference between the 610 cfs allotted for the area the demand of 666.7 cfs. Thus, there are two issues that need resolution: One is a canal capacity issue, and the other is the demand is greater than the supply (negative variance). The solution is to carry over a few of the new orders.

In Figure 8, the order for ORC-28 has been marked for carry-over by toggling the check box in the carry-over (*CO*) column. Carrying over this order reduces the Orchid flow by 13 cfs and resolves the capacity violation; this status is indicated by the orders no longer being highlighted in yellow (Figure 8) and because the variance has been reduced to -43.7 cfs. The WC should carry over additional orders to reduce the variance to approximately zero.

Once the order lineup is complete, the selected carry-overs are committed back to the TPS database by clicking the ***Update TP*** button on the ribbon bar.

Refresh Orders

When a WCDSS session is initiated, it automatically retrieves the current water-order data from the TPS database. This process may also be triggered manually by clicking the ***Refresh Orders*** button. Refreshing orders would be necessary if water orders have been added or changed in TrueCanal since the WCDSS session was started. If you have added any new delivery gates to WCDSS, it is recommended that you refresh orders. This is discussed in more detail in the **Add New Field Delivery Gate** section of this manual.

When the ***Refresh Orders*** button is pressed, a confirmation dialog box is displayed (Figure 9). There are three options available within the box: ***Keep My COs***, ***Over-write***, and ***Cancel***. When orders are refreshed, it reinitializes WCDSS to its startup state. By default, any orders marked for carry-over, but not yet committed back to the TPS database, would be overwritten by the order status as currently entered in TrueCanal. If the ***Keep My COs*** button is selected, then orders marked for carry-over, but not yet committed, would still be selected for carry-over after the orders have been refreshed. If ***Over-write*** is selected, then any carry-overs not committed would revert to the status shown in TrueCanal. Clicking the ***Cancel*** button simply cancels the operation with no action taken.

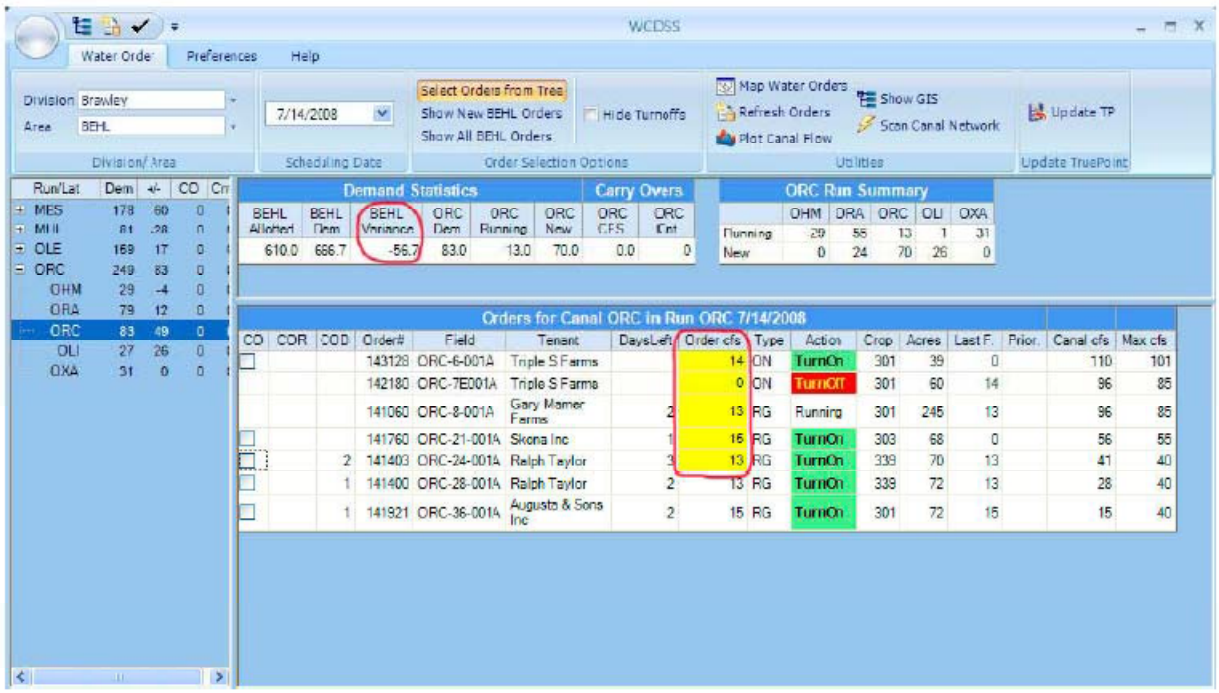


Figure 7. WCDSS screenshot showing capacity violation.

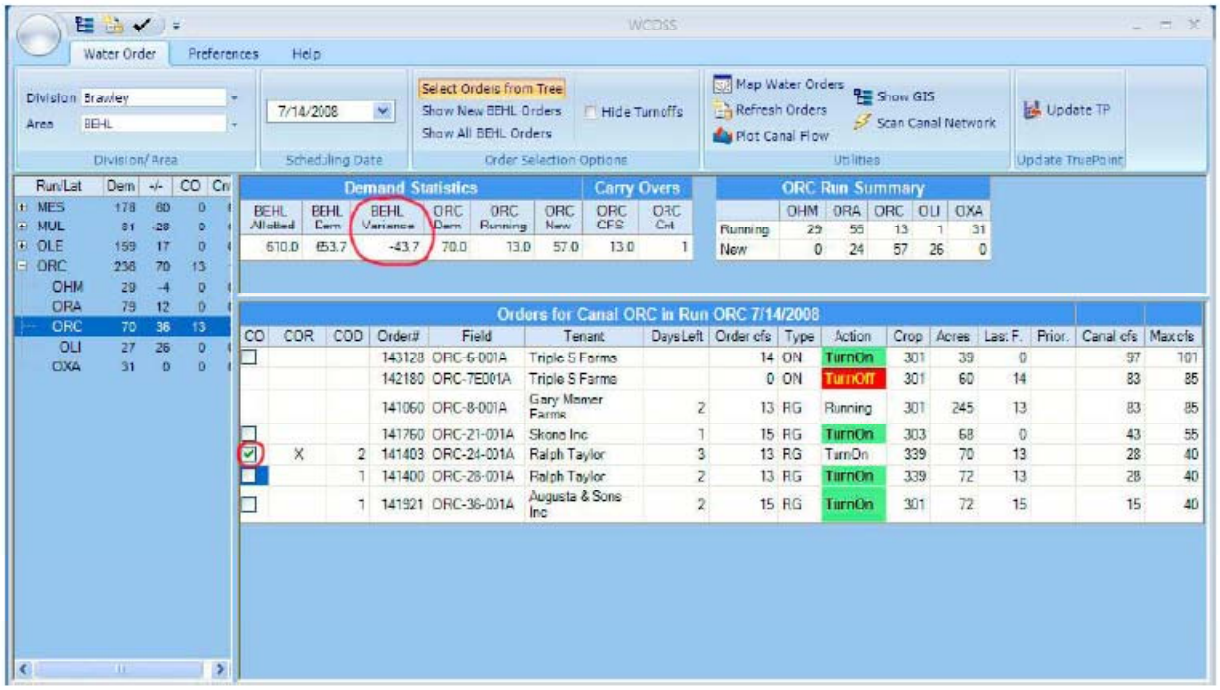


Figure 8. WCDSS screen shot showing an order that has been carried over, resulting in the elimination of the capacity violation.

Figure 9. ***Refresh Orders*** **confirmation dialog box.**

Add New Field Delivery Gate

Auto Add

When a WCDSS session is initiated, it checks the delivery gates that correspond to those orders retrieved from TruePoint against the gates in the local WCDSS database. If there is an order on a gate that is not in the WCDSS database, then the order will not be properly recognized by WCDSS. Thus, when a missing gate is detected, the user is prompted by a dialog box to add the gate (Figure 10). A selection of ***Yes*** opens the "Add Gate" utility. Clicking ***No*** will allow you to skip this part of the process and continue. However, please note that **if WCDSS is used without adding the new gate, and there is a current order on that gate, then the WCDSS demand statistics, including the variance, will not match the TrueCanal data.**

If ***Yes*** is selected, the *Add New Field Gate* form appears with the *Auto Add* tab selected (Figure 11). WCDSS locates gates with similar names so it can inherit the properties of a matching gate. The *Auto Add* feature can simplify the required data entry process for the user. Figure 11 shows that a match was found for SP 44A but not for TN 777. To add SP 44A, the user selects a matching gate by toggling the check box in the *Confirm* column. Next, the user may change the station, latitude, longitude, or reach capacity. When the user is finished updating this information, the ***Add Selected*** button should be selected; the gate is then automatically added to the remote database. The remote database and the local database are then automatically synchronized, and the results in the new gate are added to the local database.

Manual Add

If a matching gate is not found automatically, then the gate must be added manually. This process may be started by clicking on the *Step 1* tab of the *Add New Delivery Gate* form, if it is already open, or by clicking the ***Add New Field Gate*** button on the *Ribbon Bar*.

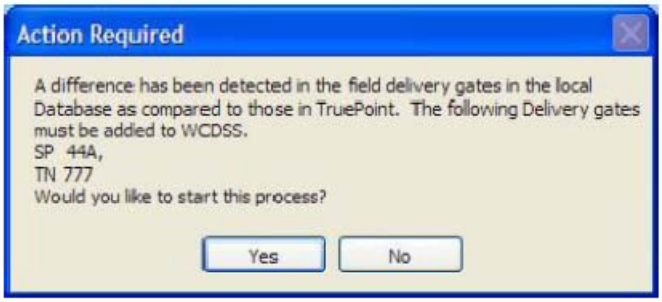


Figure 10. Prompt displayed by WCDSS when a new gate must be added to WCDSS.

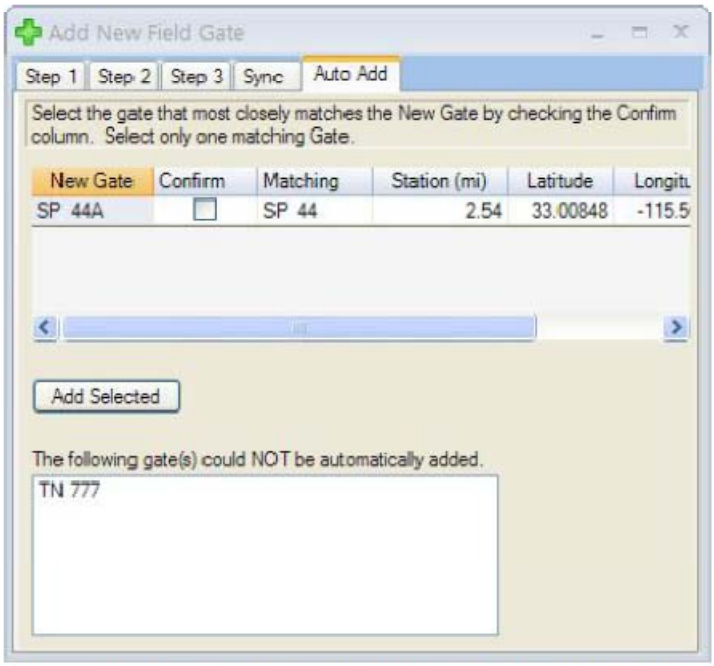


Figure 11. Auto add function of the Add New Field Delivery Gate form. SP 44A has been identified as a new gate and WCDSS has found a potential matching gate to inherit properties from. No matching gate could be found for TN 777. This gate must be added manually.

The following tutorial demonstrates how to complete the process of adding a gate manually. For demonstration purposes, we will show you how to add gate OLI 21A between gates OLI 21 and OLI 22.

1. In the *Step 1* tab window, type "OLI" in the filter box to reduce the number of gates displayed in the list (Figure 12).

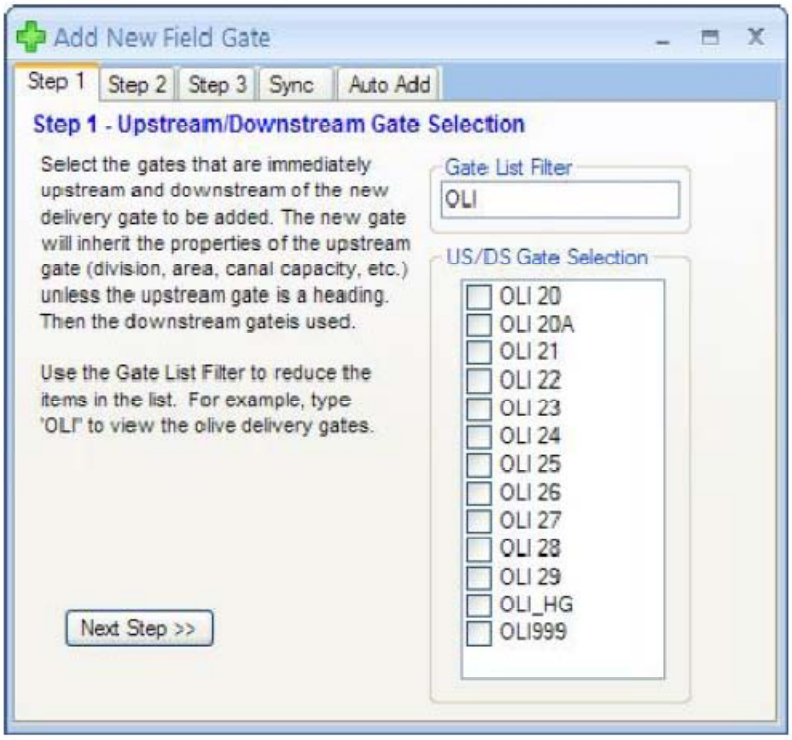


Figure 12. Add new gate—Step1.

2. Check the boxes to the left of both OLI 21 and OLI 22, and then click the ***Next Step>>*** button, which will automatically move you to the *Step 2* window.
3. In the *Step 2* window, enter the gate name (OLI 21A). It is up to you to ensure the gate name conforms to the IID gate naming conventions and matches the TrueCanal gate name. After the name has been entered, click the ***Continue*** button to the right of the field.
4. A table will display the upstream and downstream gates with the new gate falling in between (Figure 13). In the field corresponding to OLI 21A and under the *Station (mi)* column, enter a mile station value that falls between the upstream and downstream stations. If you have access to the data, enter the latitude and longitude as well; however, this sub-step is optional. Next, verify the reach capacity (*Canal Cap* column). Once these sub-steps have been completed, click the ***Next Step>>*** button, which will automatically move you to the *Step 3* window.

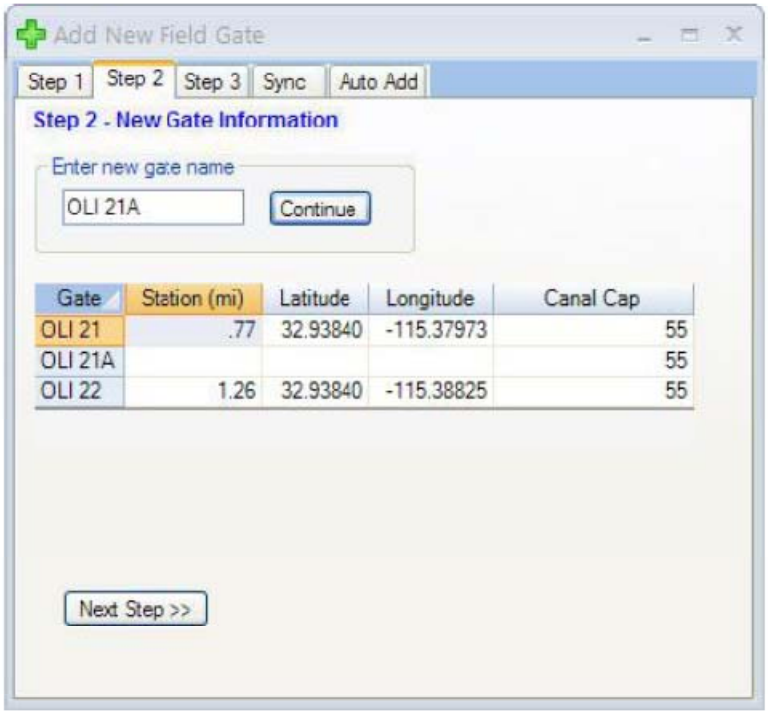


Figure 13. Add new gate—Step 2.

5. The Step 3 window displays the new gate information. If the gate information is correct, then click ***Finish.*** The gate is then added to the remote database, the remote database and local database are automatically synchronized, and the process is complete.

Synchronization

The synchronization function available on the *Sync* tab can be used at any time. Clicking the ***Sync*** button causes the gates in the remote database to be synchronized with the local database.

It is also important to note that there is no option within WCDSS to remove gates from either the local or remote databases. This has been done intentionally to prevent gates from being accidently deleted. However, if a gate is deleted from the remote database by a system administrator, the sync function will cause that same gate to be deleted from the local database as well.

WCDSS GIS

Information

WCDSS includes a simplified GIS application (Figure 14), which may be started to clicking the ***Show GIS*** button on the *Water Order* tab of the ribbon bar. It is primarily designed to allow users to easily and quickly update changes in canal capacity anywhere in the IID canal network. It may also be used to search and locate gates or IID sales areas.

This section of the document describes the operation of the GIS. A high-resolution background image is available to the user but is not installed with WCDSS due to its size (over 1 Gigabyte). If you would like access to this image, contact the IID IT department.

GIS Controls

The GIS ribbon bar consists of four groups of controls.

- Zoom/Select
  a.

Click this button to enable the Pan feature, which allows the user to pan or move around the GIS workspace by clicking and dragging.

  b.

Click this button to activate the "zoom in" tool. The cursor will change to a magnifying glass with a "plus" sign. Click on the GIS workspace to zoom in at preset intervals. Alternatively click on the workspace and drag the cursor to create a zoom window.

  c.

Click this button to activate the "zoom out" tool. The cursor will change to a magnifying glass with a "minus" sign. Click on the GIS workspace to zoom out at preset intervals.

  d.

Click this button to enable the GIS selection tool, which allows you to drag a window across the GIS workspace to select delivery gates. These selected gates are then subject to layer selection options and layer visibility options. Selected gates are displayed in a new window. See the **Modifying Reach Capacity** section of this manual for more instructions regarding this process.

  e.

Click this button to display the previous zoom setting.

  f.

Click this button to show the entire extents of the GIS workspace.

- Layer Selection
  a. ☑ Enable Gates Selection If this box is checked, all field delivery gates are eligible for selection via the selection tool.

  b. ☐ Enable Headings Selection If this box is checked, all headings are eligible for selection via the selection tool.

- Layer Visibility
  a. Refresh The refresh button turns all layers back on and shows the most current canal capacity data.

  b. ☑ Canals ☑ Canal Labels Canals/Canal Labels. If the ***Canals*** box is checked, then the canals and canal labels are displayed. When the ***Canals*** box is checked, then the canal labels can be toggled on or off independently.

  c. ☑ Gates ☑ Gate Labels Gates/Gate Labels. If the ***Gates*** box is checked, then the gates and gate labels are displayed. When the ***Gates*** box is checked, then the gate labels can be toggled on or off independently.

  d. ☑ Headings ☑ Heading Labels Headings. If the ***Headings*** box is checked, then the headings and heading labels are displayed. When the ***Headings*** box is checked, then the heading labels can be toggled on or off independently.

- Search Utility
  a. The first function of the search utility is to locate field delivery gates. For example, if "OLI" is entered as a search string and ***Search Gates*** has been checked, upon clicking the ***Run Search*** button, the Olive gates are highlighted in yellow (Figure 15).
  b. The second function of the search utility is to locate canals by area. For example, if "BEHL" is entered as a search string and ***Search Area*** has been checked, upon clicking the ***Run Search*** button, all laterals located within the BEHL area are highlighted in red (Figure 16).

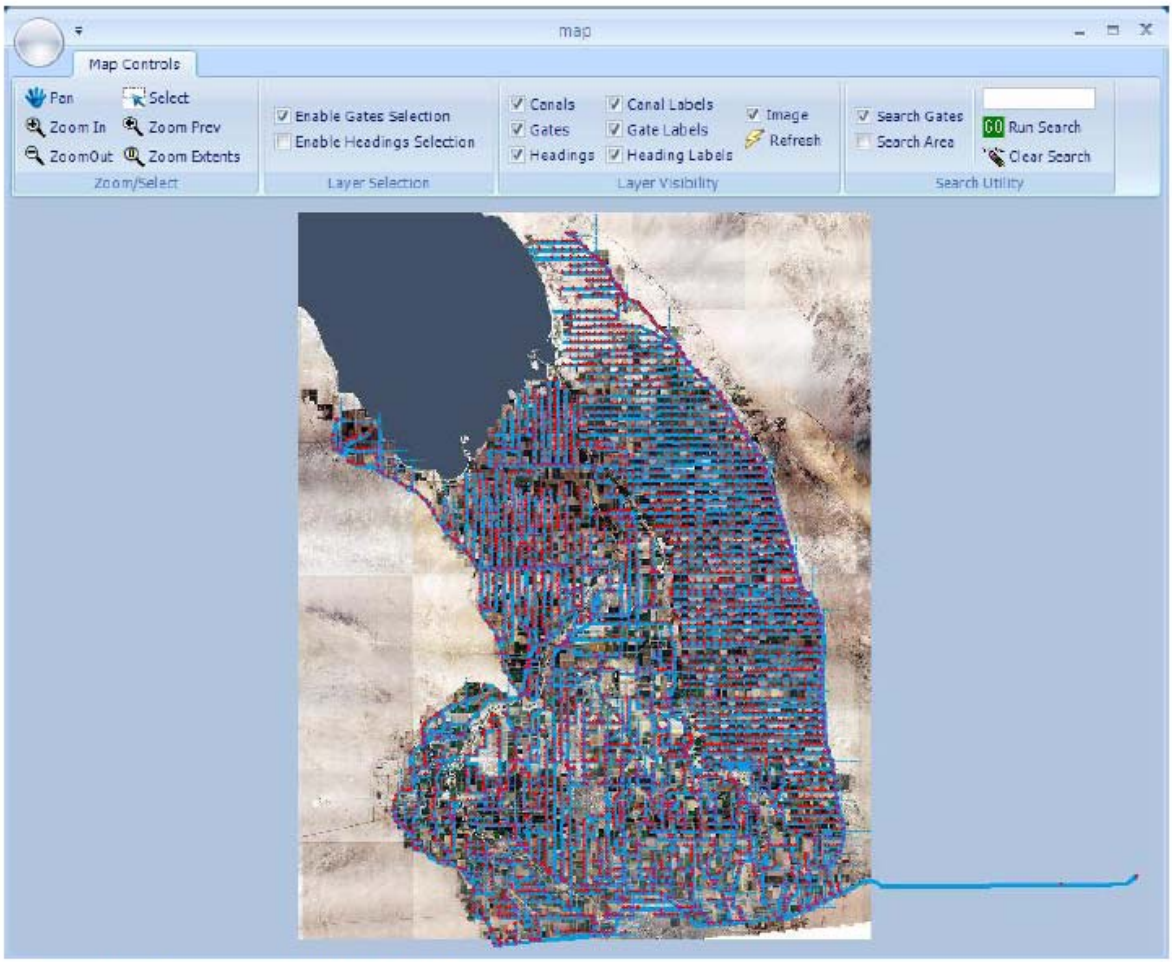


Figure 14. Example of a WCDSS GIS map.

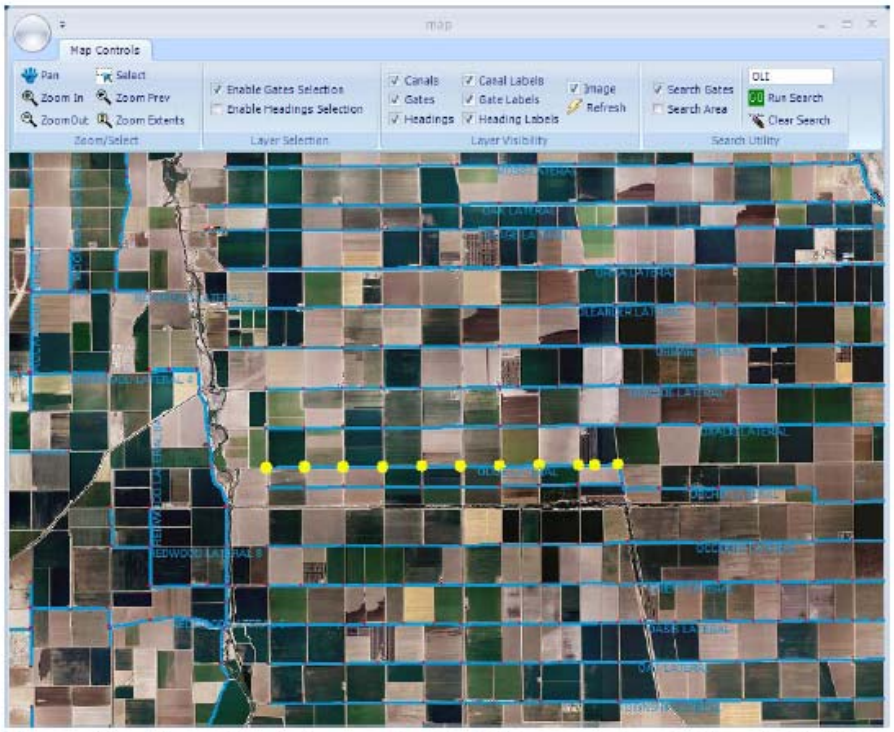


Figure 15. Example of the results of a GIS search for all Olive field delivery gates.

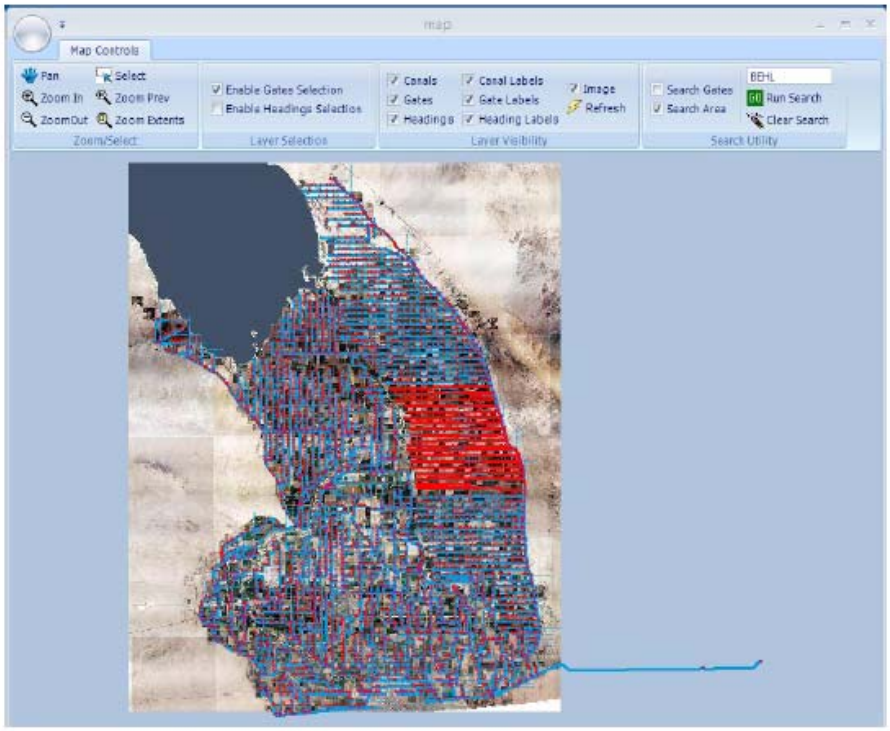


Figure 16. Example of a GIS search for all laterals in the BEHL area.

Modifying Reach Capacity

The main purpose the WCDSS GIS is to allow users to update lateral reach capacities in the canal networks. To accomplish this task, perform the following procedure.

1. Zoom into the desired area until you can easily see the gate name and lateral capacity labels on the GIS (Figure 17). The 55 cfs capacity for *OLI 20A* represents the lateral capacity in the reach upstream of the gate.
2. Ensure the ***Enable Gates Selection*** is checked and click the ***Select*** tool, both of which are located in the ribbon bar. Right click and drag a window around the desired set of gates.
3. The *Edit Reach Capacity* window will appear (Figure 18). Several columns of data are displayed but only the *Cap (cfs)* column may be edited. Change the capacity of *OLI 20A* from 55 to 50 and hit the ***Return*** key on the keyboard and close the form.
4. The canal network will then be rescanned, and a new label will appear next to old label (Figure 19). The capacity of the reach between *OLI 20A* and *OLI 20* has been changed to 50 cfs. The old label will disappear when the ***Refresh*** button is selected.
5. If *OLI 20A* is reselected, the *Cap* column will show 50 cfs. The *Des Cap* column shows the design capacity and will not change. This will always serve as a reminder as to the original capacity.
6. Because this exercise was for demonstration purposes only, please change the reach capacity back to 55 cfs if you actually changed it during the tutorial.

A canal network scan identifies a minimum upstream capacity for all reaches in the IID canal network. In this example, the OLI 20A reach capacity was changed to 50 cfs. The GIS will continue to show the reach capacity at OLI 21 and other downstream reaches at their original capacity setting. However, when the reach scan was performed in step 4 of the tutorial, it associated the reach restriction at OLI 21A with all downstream reaches. Thus, this facilitates easily changing the capacity of a reach in one location without having to change all hydraulically connected reaches.

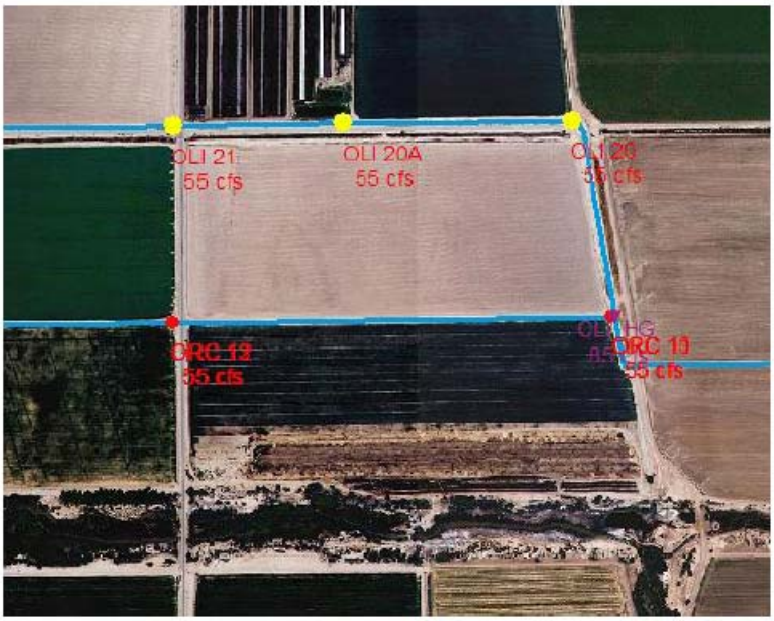


Figure 17. View of GIS showing gates and lateral capacity labels.

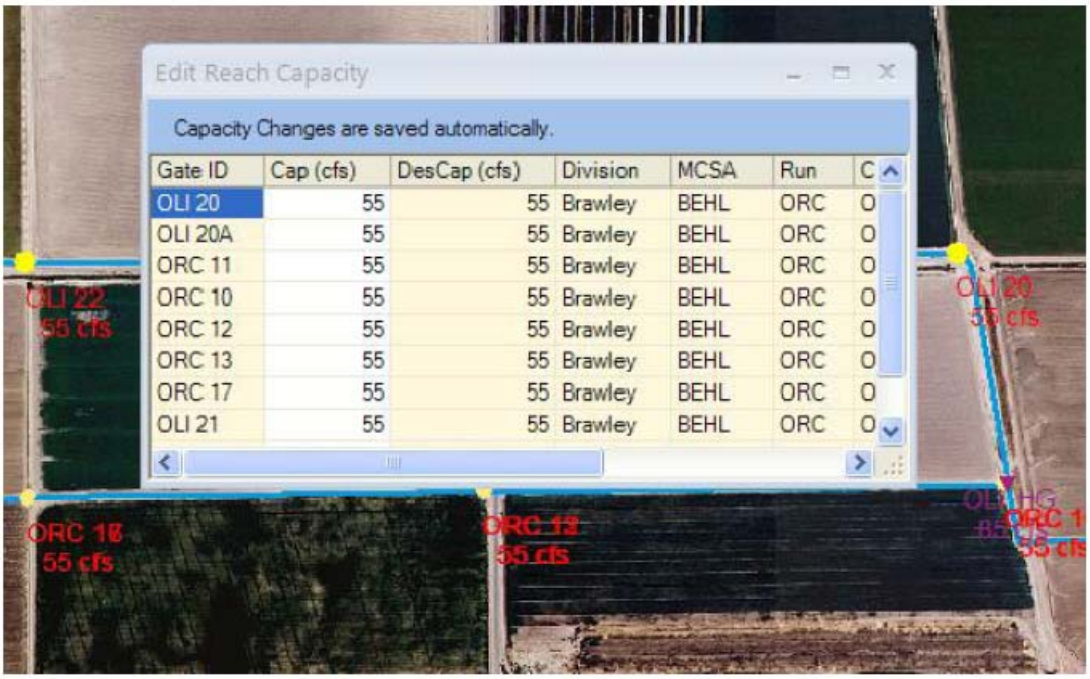


Figure 18. Edit reach capacity window showing selected gates.

Figure 19. OLI 20A capacity has been changed from 55 cfs to 50 cfs, as shown by the addition of a new label. The old label will disappear when the refresh button is selected.

APPENDIX A: WCDSS INSTALLATION INFORMATION

WCDSS requires several prerequisites. This page will guide you through the installation process. The software described in the following paragraphs will need to be installed on each machine running WCDSS. Links to download the software follow the software description. Copy and paste the URL into your browser to download each installation package. If you have problems downloading any software, please contact Keller-Bliesner Engineering. Once each software installation package has been downloaded, proceed with installation in the order of the software description as presented below.

1. **SQL Server 2005 Express (SQLExpress)**. SQLExpress is the local data store for WCDSS. WCDSS requires the SQL server replication objects that are not installed by default by the SQLExpress installer. When the *Feature Selection* page is presented during the install process, expand the *Database Services* file folder. Click on *Replication*, and then click *Entire feature will be installed on local hard drive*. Finally, you will be asked to pick the authentication type. Please select *Windows Authentication*
   http://go.microsoft.com/fwlink/?linkid=65212

2. **SQL Server Management Studio Express**. This is a free SQL Server management utility that is needed to restore or attach the WCDSS database to SQL Server Express, which was installed in the previous step. To install, run the installation package.
   http://go.microsoft.com/fwlink/?linkid=65110

3. **Version 3.5 SP1 of the .NET Framework**. This is the most recent version of the .NET Framework and is required for WCDSS to run. To install, run the installation package.
   http://www.microsoft.com/downloads/details.aspx?FamilyId=AB99342F-5D1A-413D-8319-81DA479AB0D7&displaylang=en

4. **MapWindow GIS Component**. WCDSS has built-in GIS capabilities that require the MapWindow component. To install, run the installation package. The OCX component installed must be registered with the operating system; thus, a computer restart will be required. http://www.keller-bliesner.net/iid/MapWinGIS46OCXOnly.exe

5. **WDSSSQL Database**. Please contact Keller-Bliesner Engineering for the location of the most current copy of a WCDSS backup database. The backup database will need to be restored to each computer running WCDSS using SQL Server Management Studio Express, installed previously.

6. **WCDSS Installation**. WCDSS is installed via a web-based installation process. Note that Internet Explorer is required. Other browsers such as Firefox will not properly complete the install. You can begin the installation process by going to the following URL: http://www.keller-bliesner.net/software/WCDSS/ClickOnce/publish.htm.

APPENDIX B: WCDSS SETTINGS

This section is designed for the IID IT Department and specifically the SQL Server database administrator (DBA).

WCDSS Settings (Figure B-1) controls how WCDSS interacts with external data sources such as the TPS database and the local SQL Server Express database. Getting these settings correct is critical to the operation of WCDSS. These settings are typically only to be adjusted by the DBA. The following sections in this appendix describe the WCDSS settings. To better understand these settings, a brief background in replication and web services is provided.

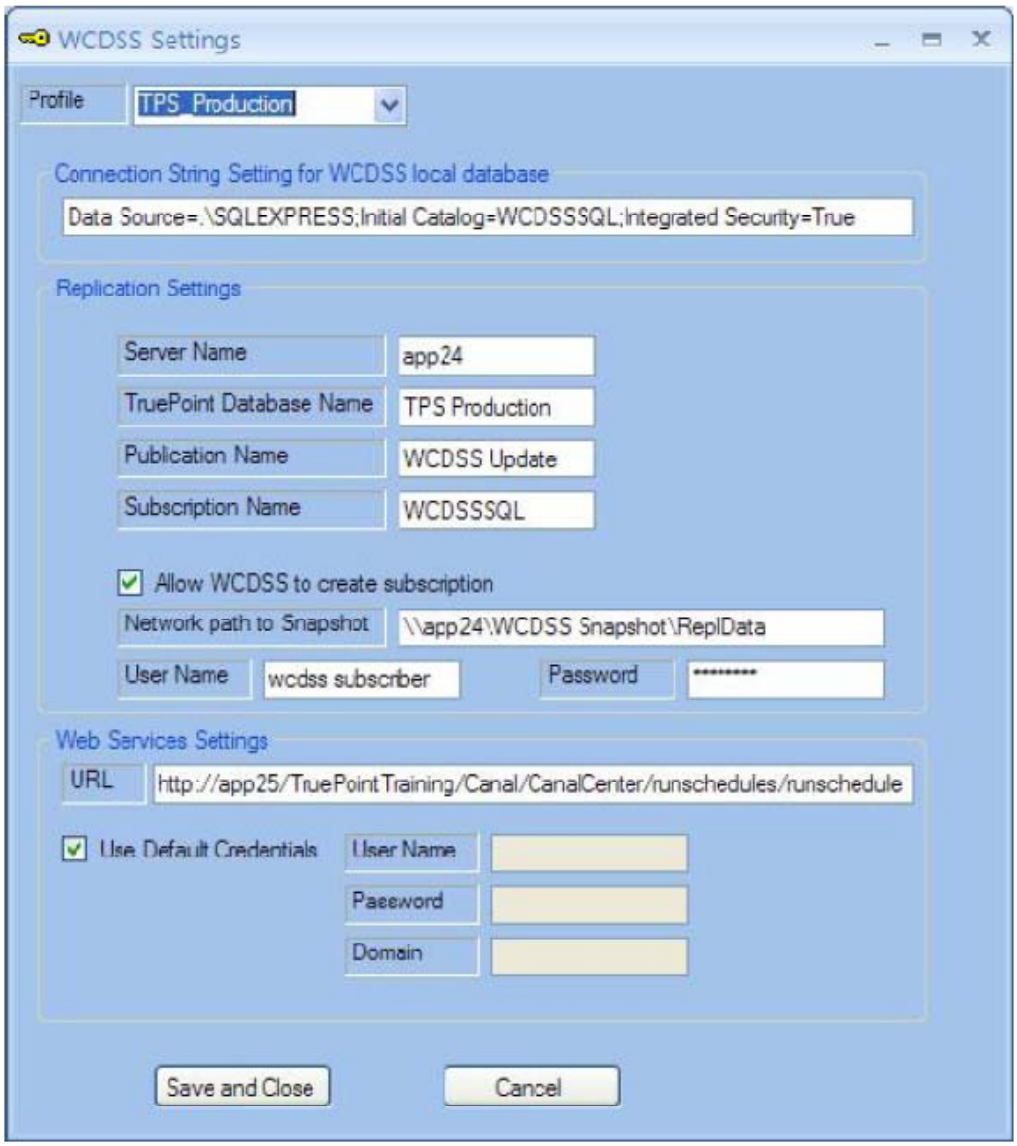


Figure B-1. WCDSS Settings window.

What is Replication

Retrieval of water-order data from the TPS database to the local WCDSS database is completed through a process called transactional replication and is performed via SQL Server and SQL Server Express. A SQL Server publication is created for the TPS SQL Server database that contains water order information that WCDSS requires to run. Each computer that runs WCDSS also has an instance of SQL Server Express running to which the WCDSS database is attached. The WCDSS SQL Server Express database subscribes to the TPS publication and data is transferred from SQL Server to the local WCDSS database on each computer

When replication is setup, an initial snapshot is taken of the schema and data you want to publish. Before a subscriber can receive incremental changes from the publisher it must contain the same table schema as the data being published.

Once replication is initiated on SQL Server, the Log Reader Agent runs at the Distributor continuously. You can see this in the SQL Server Job Activity Monitor. Look for "Server name" – TruePoint-1" with a category of "REPL-LogReader". The Status should be executing. The Log Reader Agent first reads the publication transaction log and identifies any INSERT, UPDATE, and DELETE statements, or other modifications made to the data in transactions that have been marked for replication. The agent copies those transactions in batches to the distribution database at the distributor. We named this database "distribution", and it should be in data directory of the SQL server installation.

The distribution database then becomes the store-and-forward queue from which changes are sent to Subscribers. Only committed transactions are sent to the distribution database. Transaction commands are stored in the distribution database until they are propagated to all subscribers or until the maximum distribution retention period has been reached.

When WCDSS runs, it programmatically triggers the local instance of SQL Server Express to download or pull the data from the distributor. WCDSS uses a "pull subscription" where data is pulled by the client, as opposed to a "push subscription" where data is pushed from the distributor.

The appropriate replication settings for WCDSS are described in the **Settings** section below.

What are Web Services

The other functionality of WCDSS controlled by the settings is access to the TPS web services used to carry over orders. TrueCanal employs a web service written by TPS to make the necessary changes in the TPS database. With TPS permission, WCDSS uses the same web service to carry over orders. Web service settings are described in the **Settings** section.

Settings

Profiles

Different settings may be needed based on the WCDSS installation scenario. For example, during testing WCDSS may be configured to use a profile that points to the TPS training database. To use WCDSS in the production environment, a different set of settings are required. Four independent profiles may be saved.

Connection String Settings for WCDSS Local Database

- Connection String. This setting designates the connection string to local SQL Server express database and is provided by Keller-Bliesner Engineering.

Replication Settings

- Server Name. This setting designates the name of the server hosting the TPS database.
- TruePoint Database Name. This setting designates the SQL Server TPS database name.
- Publication Name. This setting designates the name of the publication on SQL Server.
- Subscription Name. This setting designates the name of the subscription on SQL Server Express.
- Allow WCDSS to create subscription. If this option is checked, WCDSS can programmatically connect to SQL Server Express and create the needed settings for the subscription. Two items are needed: the network path to the replication snapshot and the credentials to connect to SQL Server. These settings can also be entered in SQL Server Express manually.

Web Services Settings

- URL. This setting designates the URL for the web service.
- Use Default Credentials. If this box is checked, then default user credentials are used. Users on the IID network who have received permission from the IT department to use WCDSS will, by default, have the necessary credentials to access the web services. Users who access internal resources via a VPN (Virtual Private Network) will have to provide the appropriate credentials as supplied by the IT department.

APPENDIX 2B:
Data Entry with Tablet PCs

Figure 2B-1 shows a flow chart with the specific steps taken for the data entry phase of this project.

Figure 2B-1: Flow chart of data entry with tablet PC's product development

The third link in the development of irrigation district scheduling and routing DSS tools was an attempt to streamline the data entry process for water orders. ITRC personnel observed the process of how water orders were received by IID Water Coordinators in the division offices. It was very apparent that there was huge room for improvement due to unnecessary duplication of work and the high probability of errors. The following is a brief outline of how the existing water ordering process works:

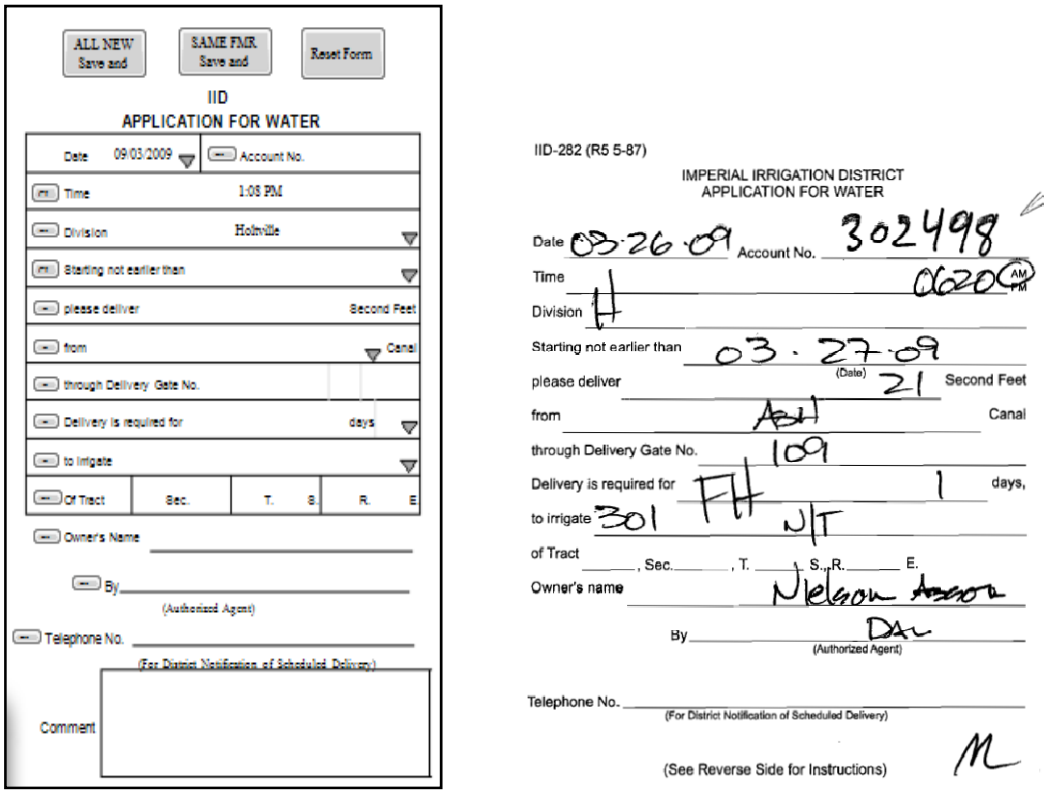
- A phone call comes in to the IID office for a water order for the next day or to cancel an earlier placed order (before noon)
- A phone operator quickly scribbles the order onto a paper form (or several forms depending on number of orders per customer) and puts it to the side with other forms
- Sometime before the end of the day when the Water Coordinator has some time available, the information gets entered into TruePoint software
- The Water Coordinator determines which orders to fill and which to carry over (and this information is entered into TruePoint)

In order to streamline this process, ITRC felt that an electronic data entry form that could be filled out with electronic handwriting would be a useful tool for Water Coordinators. The potential benefits of utilizing a digital water ordering form via tablet PCs include:

- *Reduction in the number of manual tasks* – By directly inputting the information into the tablet PC, one entire step of the water ordering process is eliminated (handwritten paper forms). Information input to the digital form would be instantly sent to a database linked to IID's main TruePoint database, speeding up the transfer of information to the water coordinator. Additionally:
    - The tablet PC's digital form would have the ability to show pull-down menus ("pick lists"), which further reduces the amount of handwriting/typing.
    - Every digital form could be automatically time stamped (again, reducing the amount of handwriting/typing required).
- *Reduction of errors* – These could include typing errors or misreading poor handwriting. With a tablet PC, data that was input into the digital water ordering form by the telephone operator could be immediately viewed in its final form. Therefore, the operator would have the opportunity to immediately verify the accuracy of the information.

Based on these potential benefits it seemed that a tablet PC would be a good solution. ITRC researched various tablet PC manufacturers and models, and eventually selected the Lenovo Thinkpad. ITRC used a software package called Active Ink that provided the platform for building a digital water ordering form. After purchasing the software, a form was created to closely match the paper one used by IID personnel (see **Figure 2B-2**).

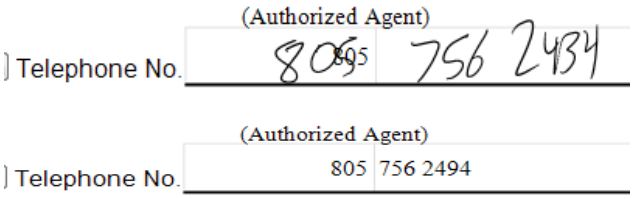
Figure 2B-2: Digital water ordering form on left, standard paper form on right (filled in by IID telephone operator)



The next step was to test the data entry function on the tablet PC. Unfortunately, ITRC ran into many problems with both the tablet PC and the Active Ink software. Several of the features that were envisioned were not standard tools in the software, which resulted in expensive customization of the Active Ink software. ITRC worked closely with the Active Ink representatives to get the features that were required. It proved to be expensive and imperfect. Some of the problems that were encountered with both the tablet PC and Active Ink software are listed below:

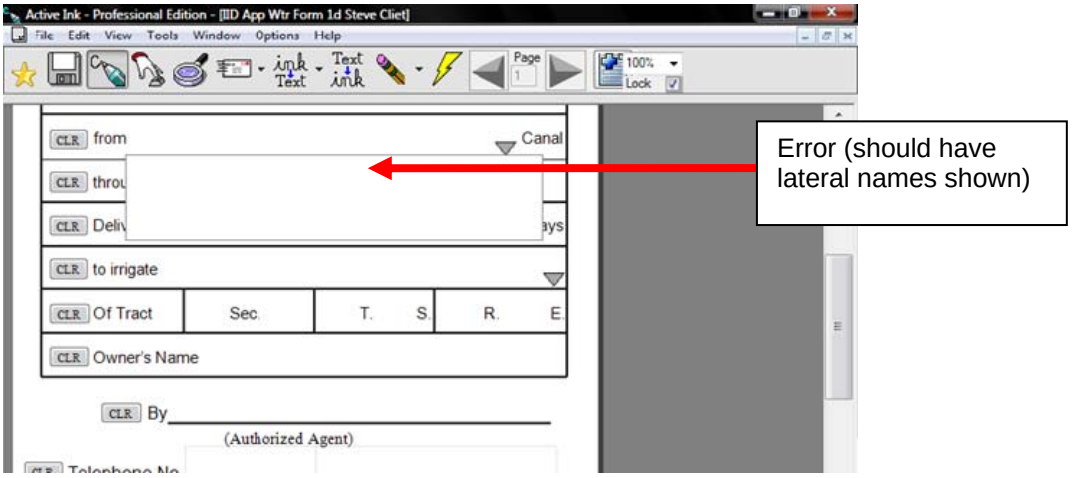
1. *Handwriting recognition*: Since the handwriting recognition software is relatively sensitive, frequent errors occur during the process of filling out the form. Refer to the example in **Figure 2B-3** showing the software's inaccuracy recognizing a phone number.

Figure 2B-3: Tablet PC handwriting recognition problems



2. *Pull down menus (pick lists)*: When a user clicks on a pull-down menu in the data entry form, a drop-down list should appear that would allow rapid data entry with no room for typing error. For some unknown reason(s), occasionally the drop-down menu would come up blank, and sometimes it would appear correctly (see **Figure 2B-4**).

Figure 2B-4: Pick list error



3. *Speed*: When ITRC attempted to input data as quickly as the office staff at IID do, the tablet PC had trouble keeping up.

4. *Time Stamp*: ITRC found that the time stamp was not such an easy task for the Active Ink program to display. This required an expensive add-on to get the time stamp inserted into the digital form correctly.

5. *Compatibility*: ITRC realized that it would require a large effort from both Active Ink and TruePoint in order to enable the two databases to work together.

6. *Operating System*: There was an operating system incompatibility (64-bit version of Windows Vista had to be downgraded to a 32-bit version in order to work properly).

7. *Erasing Function:* For unknown reason(s), the eraser would not work if the brightness of the screen was set at 100%. If turned down to 99% or lower, it would work.

8. *Computer Crashes*: ITRC found that the tablet PC experienced frequent crashes. This was not acceptable due to the high frequency of phone calls that the IID office receives.

Along the way, ITRC thought that the software problems might be solved with a different software package. Therefore, several comparable software options were reviewed that could serve as an alternative to Active Ink. The various options were:

- Design Universe E-Pen & Forms Builder for tablet PC
- RightScript, Ritepen
- Nuance OmniForm
- Microsoft Infopath

However, it appeared that all of the brands of software were similar in the services that were provided and there appeared to be functionality problems with each one based on user reviews. Therefore, no other brand of software was chosen, due to the high cost of customization and the seemingly small chance of success.

It was found that if either the operator takes the time to write neatly and wait for the pick lists to show up, or if the form was revised to provide a box for each digit to be entered into, it is possible for the form to be correctly filled out. The problem is that IID staff require speed and accuracy above all else. Speed and accuracy are extremely important, because there is a farmer on the other end of the telephone who does not want to wait for the computer to process the information. The farmer wants to give information quickly, and then get off the phone. Since there is a high volume of water orders received every day (plus cancel orders), there is no extra time to wait for the tablet PC to recognize text or restart after a crash.

ITRC realized that it would quickly frustrate both the Water Coordinator and customers to have to slow down and/or retype the information, which would most likely result in them reverting back to their traditional method. Therefore, it was determined that the tablet PC was far too slow and inconsistent.

Other issues that increased the complexity beyond the practical limit of the tablet PC were:

- IID's naming convention:
    - "Canal name" and/or "gate number" typically consist of a series of numbers and letters. It would most likely be simpler (reducing handwriting recognition errors) if the values were restricted to either only numbers or only letters.
    - The account number is generated internally by the TruePoint software when the operator starts to fill out the form. The "account number" is actually more like a water order number and varies each time that water is ordered for each farmer.
- The same farmer may have several different accounts.
- Several farmers may be served by the same turnout.
- The numbers of days of irrigation requested are not always full calendar days. For example, IID uses letter codes to specify the specific times when to turn water on/off.
- In the end, there were too many variables, which greatly slowed down the process of data entry into the tablet PC.

While it is possible to have the tablet PC trained to recognize a specific person's writing, it was still not robust enough to satisfy all of the requirements. ITRC personnel went through a lengthy process of teaching the software to recognize a specific person's handwriting. However, the errors were still too frequent when converting the handwriting to text.

APPENDIX 2C:
Definitions

Throughout this report and its appendices, the following words and acronyms are used:

Art	Logic/reasoning learned through experience that is non-transferrable to new employees, and usually not detailed in written documentation
Carryover	A water order that cannot be filled when requested and is postponed for a certain time period (e.g., 1 day) based on district rules/policies
DSS	Decision Support System
GIS	Geographic Information System
HMI	Human Machine Interface
IIM	Integrated Information Management
LDSS	Lateral Decision Support System
PLC	Programmable Logic Controller
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
WCDSS	Water Coordinator Decision Support System
WIS	Water Information System
Zanjero	Irrigation district employee who delivers water to the farmers (basically, a ditch tender)

APPENDIX 3A:
Commercial Sand Media Filter Tank Criteria for Energy Efficiency: Agricultural Drip Irrigation

Background

Sand media filters are commonly used in agricultural drip irrigation systems. They have the advantages of simplicity and large capacities, and are favored by many farmers and designers over other filtration hardware.

The primary justification for the research described in this report was to determine if it is possible and reasonable to use lower-than-accepted backflush pressures and thereby reduce the total pressure requirement for drip systems. Common design lore by manufacturers and irrigation dealers indicates that for media filters to backflush properly, at least 30–35 psi is needed downstream of the filters. This high pressure requirement can exceed what is needed for the combination of other system components and conveyance within a drip system – especially for row crop drip systems that have tapes operating in the 8-10 psi range.

ITRC designed and performed a series of hydraulic tests on several different commercial sand media filter tanks (one unit of each of five models). The testing provided the following results:

1. There are substantially different friction losses across filters of different designs at different times:
    a. During backflush
    b. During filtration
2. The primary pressure loss location is the backflush valves.
3. Large backflush flow rates can be accomplished at relatively low backflush pressures. This assumes correct backflush water discharge piping.
4. There are substantial differences between underdrains of various media tank models, regarding:
    a. The percent open area
    b. The uniformity of the sizes of the openings in the slots/wands
    c. The configurations of the slots/wands, including:
        i. Positioning of slots/wands around the bottom of the tanks
        ii. Height of slots/wands within the tanks
5. No large initial high pressure was necessary during the ITRC testing to "break up the media bed" when backflush began.
6. Different underdrain designs create different patterns of cleaning the media.
7. There were substantial differences between models, regarding the amount of sand discharged from the system at a backflush flow rate of 190 GPM.

Media Tanks Tested

Five different tanks were obtained from four manufacturers. Only two tanks were tested over an extended period of time with contaminants, due to the complexity of those tests and the large amount of time needed. The various tanks are described individually below. Lakos later provided a tank with a modified, newer underdrain for some tests (listed as "newer design" in this report).

Manufacturers modify their designs over time, and these tests were meant to investigate various *designs* – as opposed to attempting to compare *manufacturers*. Also, considerations such as corrosion, strength of tanks, longevity of valve actions, sensitivity to damage during transportation, and cost were not evaluated in this project. The intents of this publication are to increase awareness of how these important filters work, and to indicate factors that might be modified to improve their performance.

Table 3A-1 provides basic information for each tank. All tanks were 48" nominal diameter, and rated at 80 psi by the manufacturers.

Table 3A-1: Information supplied by manufacturers

	Arkal (Netafim)	Flow-Guard (Fresno Valves & Castings)	Lakos	Waterman	Waterman
Model	AGF – 48"	SS – 48"	SST – 48"	Wand	Dome
Underdrain material	Plastic	Stainless steel	PVC plastic	Plastic	Plastic
Backflush flow rate (GPM)	176 - 264	200	188	Not provided	Not provided
Filtration flow rate (GPM)	220 – 313	213 – 313	220 – 313	Not provided	Not provided
Minimum backflush pressure (psi)	28	Not provided	20 – 80	Not provided	Not provided
Media sand requirement (lb)	1200	1300	1300	800*	800
Gravel requirement (lb)	None	560	None	Not stated	Not stated

*The Waterman Wand had a recommendation of 800 lb of media, but ITRC added an additional 7.5 cm. of media depth to provide cover over the wands. The 800 lb would have only provided 2.5 cm of cover at the most shallow point.

Exterior and Interior Views of Tanks

Figures 3A-1 through 3A-5 show the various tanks that were tested.

Figure 3A-1: Arkal AGF exterior and underdrain

Figure 3A-2: Flow-Guard exterior and underdrain

Figure 3A-3: Lakos exterior and underdrain

Figure 3A-4: Waterman Wand ("spike") exterior and underdrain

Figure 3A-5: Waterman Dome exterior and underdrain

These photos provide views of the underdrain designs and positioning near the base of the tanks. ITRC noticed the following upon delivery of the tanks:

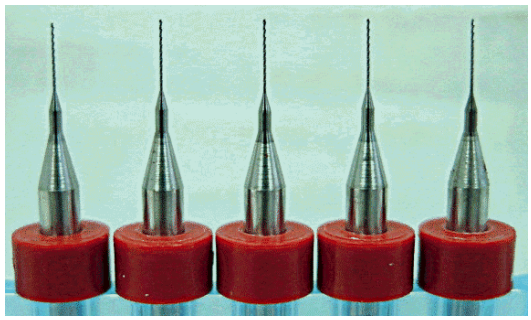
1. The Waterman Dome appeared to be missing several pods, as can be seen in **Figure 3A-5**. The tank was tested as-is.
2. One of the pods for the Arkal filter was broken. That pod was replaced before testing.

Underdrain Characteristics

Total Slot Open Area

Micro drill bits (e.g., Item #08WS97-90 from Drill Bit City) were used to measure underdrain slot open widths. Approximately 120 measurements were made for each filter. Because the drill bits have discrete sizes, the accuracies of the slot width measurements are only within +/-2%.

Figure 3A-6: Example micro drill bits



At the start of the testing, it was thought that the total slot open area might be an important indicator of:

1. Pressure requirements for backflushing.
2. Uniformity of cleaning the media bed during backflush.

Table 3A-2 provides a summary of measurements regarding the underdrain slots. It can be seen that there are substantial differences in:

1. *Total slot open area.*
2. *Standard deviation of slot widths* (a large standard deviation indicates large differences in slot widths; with a "normal" distribution of widths, 95% of all slot widths should fall within +/- 2 standard deviations of the mean). Statistically speaking, one might expect 95% of all Flow-Guard slot sizes to fall between 0.165 mm – 0.291 mm. In fact, the absolute range of all measured sizes was 0.180 mm – 0.279 mm.
3. *Mean slot widths*. It might be noted that a large total slot area can be achieved by having a relatively smaller number of slots.

Table 3A-2: Underdrain slot characteristics

Tank	Total # of pods or screen sections	Mean slot width, mm.	Std. dev. of widths, mm.	Total slot open area, sq. cm.
Arkal	55	0.330	0.036	200
Flow-Guard	19	0.233	0.029	184
Lakos (original)	27	0.307	0.107	405
Lakos (newer design)	25	0.273	0.036	261
Waterman Dome	45	0.292	not meas.	108
Waterman Wand	16	0.189	0.026	343

Figures 3A-7 through **3A-11** show close-up views of each underdrain pod or screen section.

Figure 3A-7: Arkal pod design. The photo with the pod arms shows a broken pod

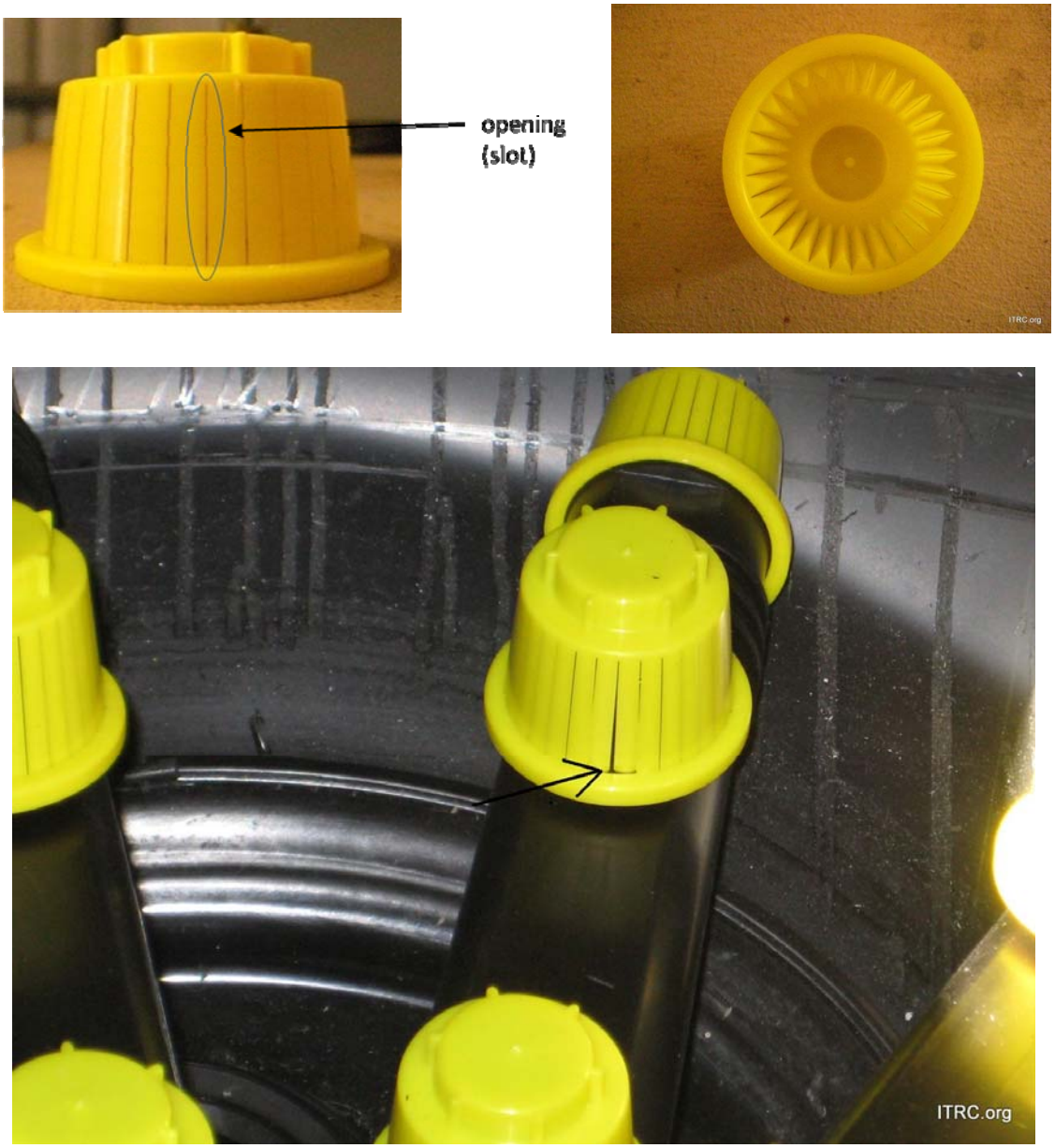
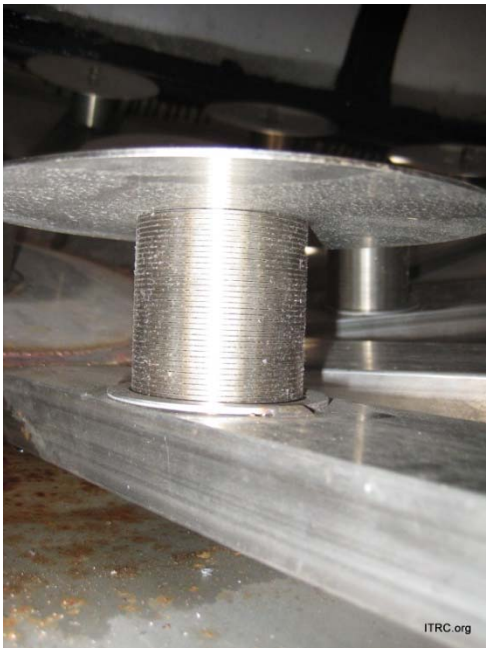
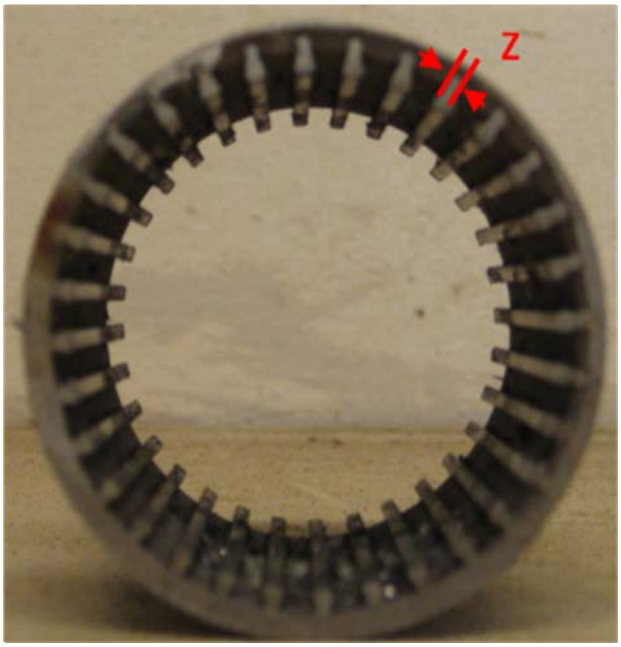


Figure 3A-8: Flow-Guard underdrain. Pods are found under the flat stainless disks.





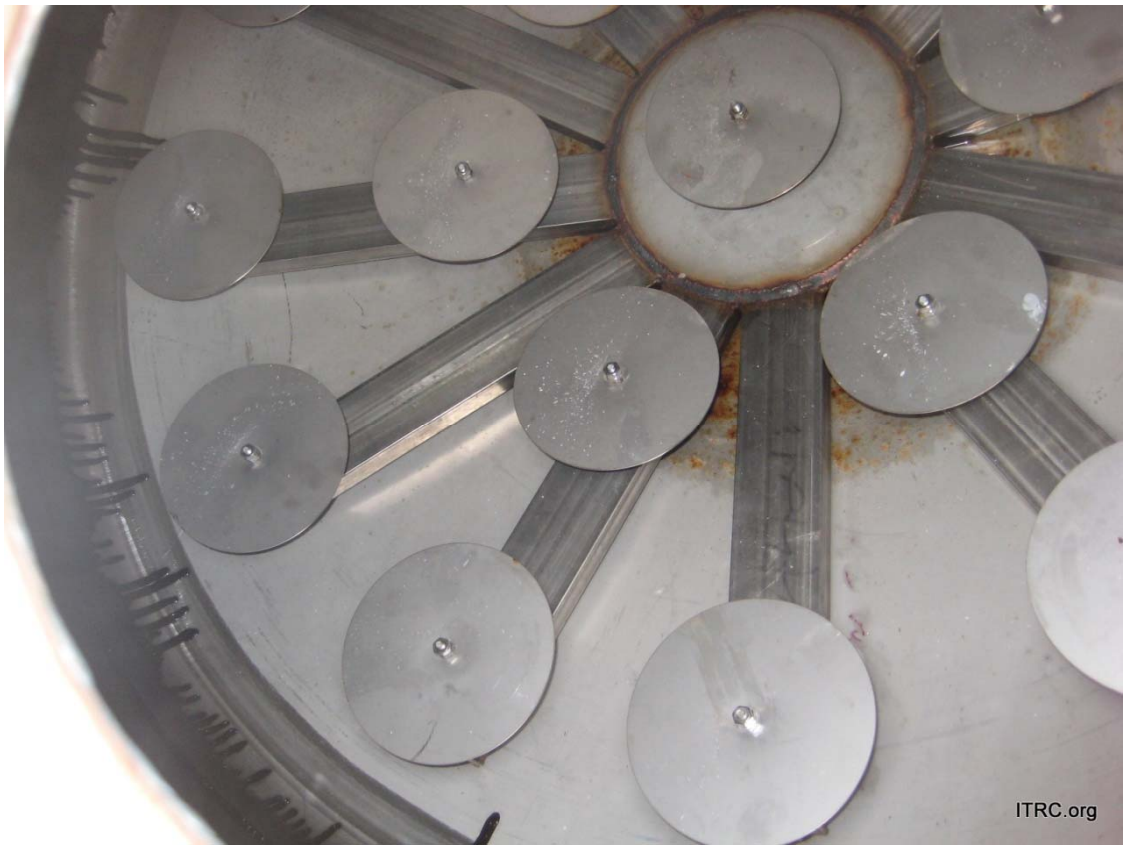


Figure 3A-9: Lakos underdrain. The longest wands have a non-perforated PVC pipe section near their inlets.

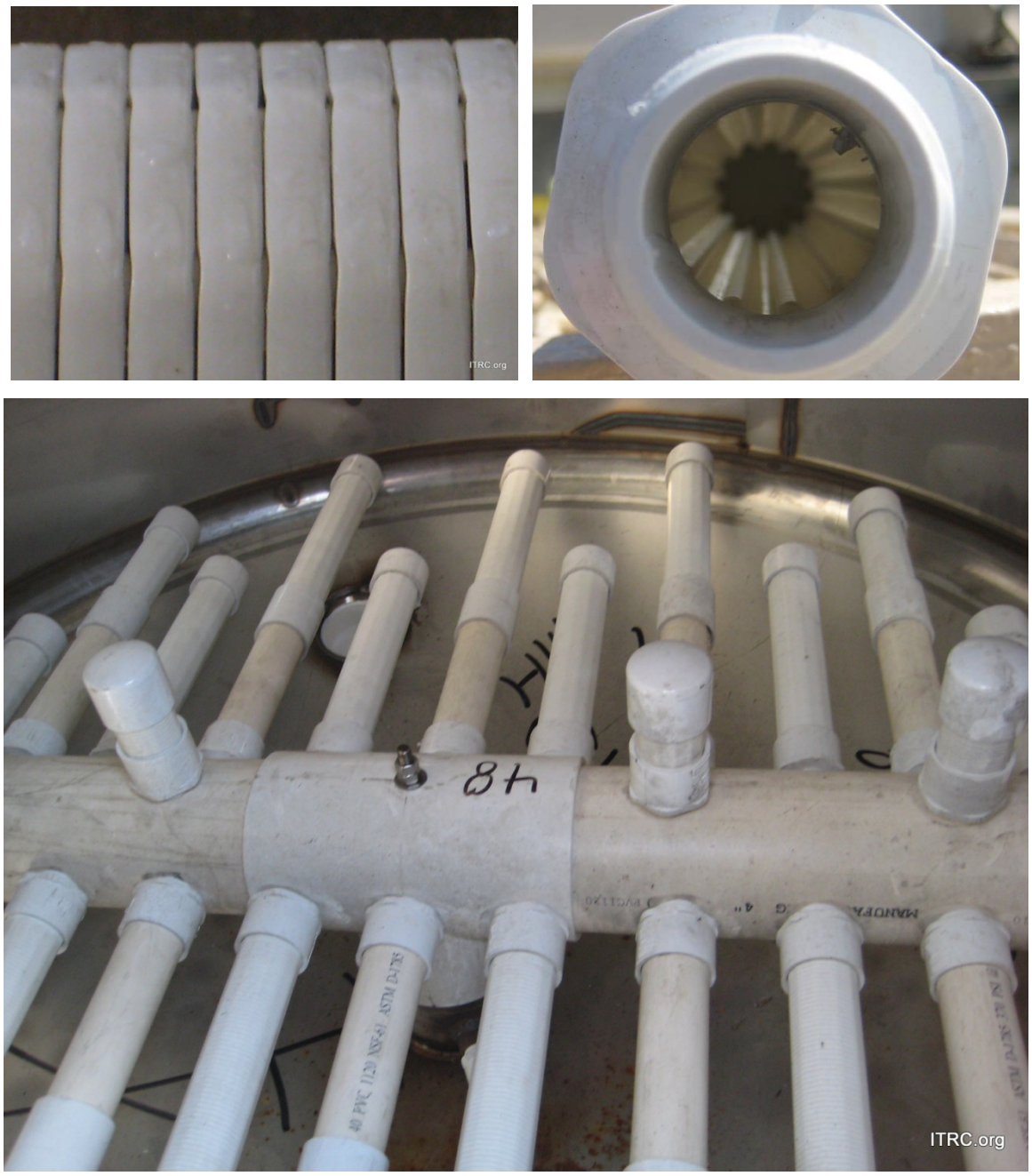
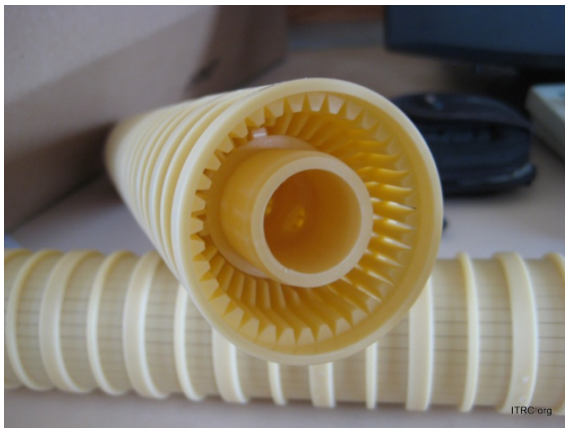
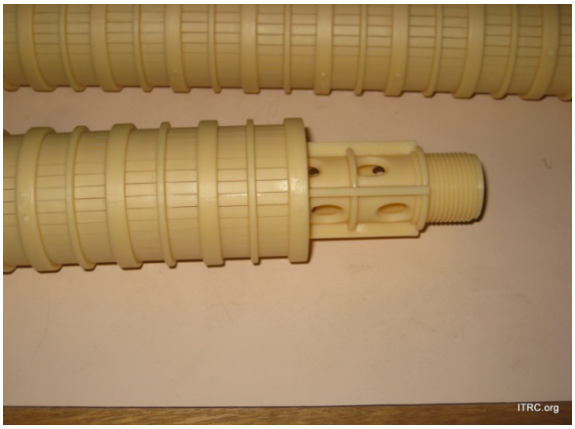
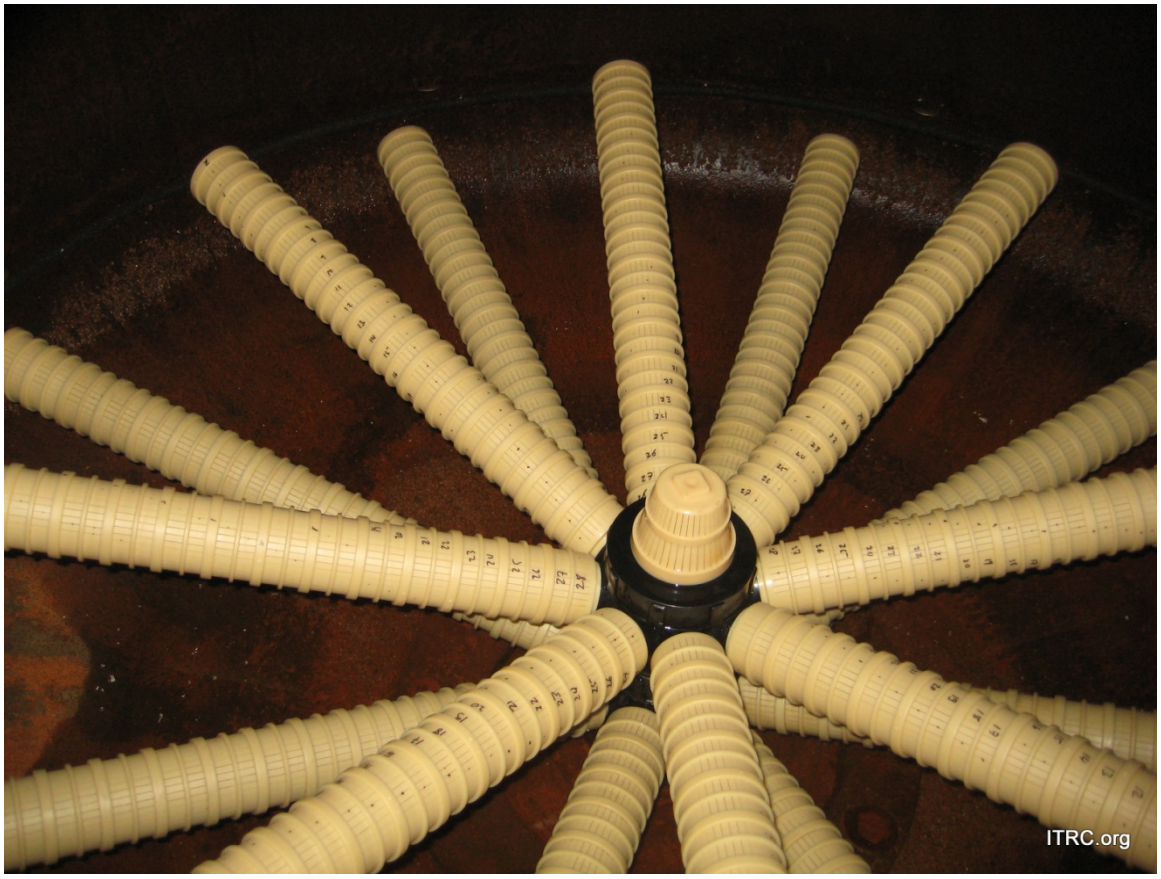


Figure 3A-10: Waterman Dome underdrain. The pods are at different heights, due to the shape of the inverted dome. Photo shows at least 3 locations where pods were expected to be found but were not installed.

Figure 3A-11: Waterman Wand ("spike") underdrain. The top wands are shorter than the lower ones; slots are found along the complete length of each wand.







Horizontal Distribution of the Slots across the Bottom of the Tanks

It was hypothesized at the start of the tests that an even and dense distribution of slots across the bottom of a tank would be beneficial in providing a uniform cleaning of media during backflushing.

For each of the tanks, areas of responsibility were assigned for each pod or open wand area. Sketches were developed and areas were computed, as shown in **Figures 3A-12** through **3A-16**.

Figure 3A-12: Arkal pod arrangement

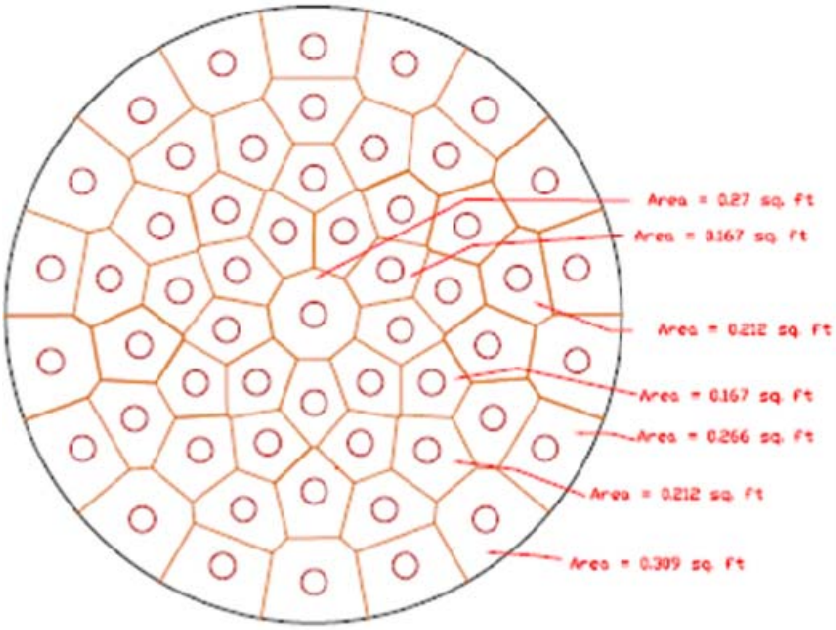


Figure 3A-13: Flow-Guard pod arrangement

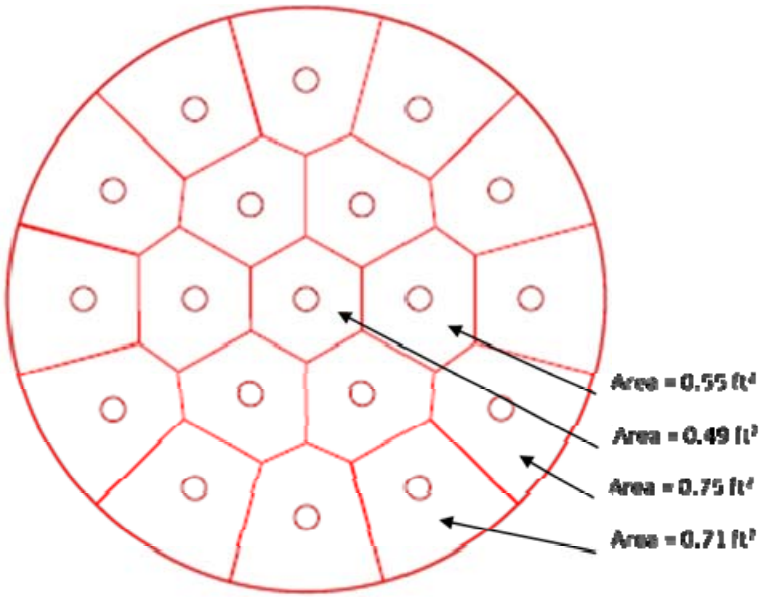


Figure 3A-14: Lakos open wand arrangement

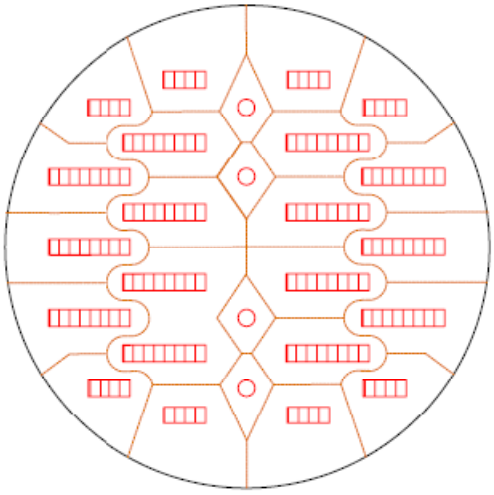


Figure 3A-15: Waterman Dome pod arrangement

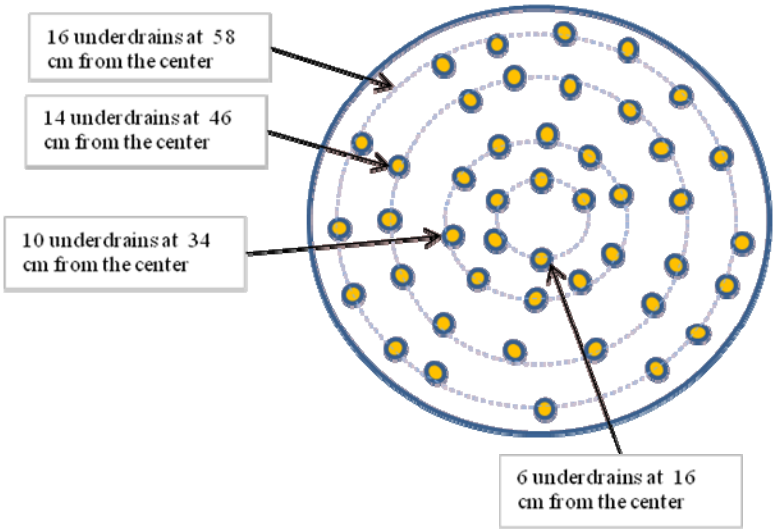


Figure 3A-16: Waterman Wand arrangement

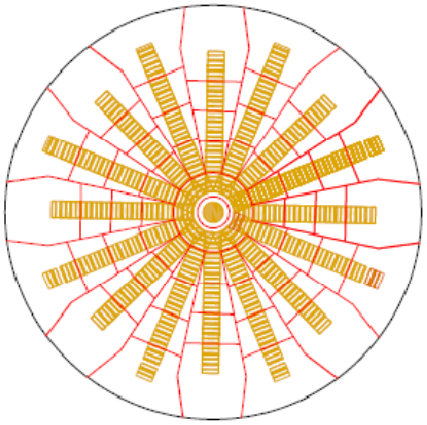


Table 3A-3 shows the variation in horizontal tank area served per unit of open underdrain, for each of the models examined.

Table 3A-3: Horizontal area served by underdrain units

	Average area served, sq. cm. per unit	cv
Arkal	214	0.24
Flow-Guard	613	0.14
Lakos	446	0.31
Waterman Dome	214	0.17
Waterman Wand	177	0.75

The "cv" in **Table 3A-3** is the coefficient of variation, which has no units or dimensions, and is defined as:

$$\text{cv} = \frac{standard\ deviation}{mean}$$

where 95% of the values are expected to approximately fall within +/- two cv's of the average. For example, if the Waterman Dome had a normal distribution of areas per pod, almost all of the values should fall between 141 cm^2 - 287 cm^2. A small cv indicates a very uniform horizontal distribution of pods/units.

The average area per unit may be misleading if examined alone. For example, a very long single wand, with many holes, might be responsible for a large area. An "Area covered ratio" was developed to indicate the percent of a horizontal plane that is occupied by pods or wands.

$$\text{Area covered ratio} = \frac{Horizontal\ area\ occupied\ by\ pod\ or\ wand\ with\ slots}{Total\ surface\ area}$$

Fraction of a horizontal plane that is occupied by pods or slotted wands

Table 3A-4: Fraction of the horizontal area covered by pods or slotted wands

Tank	Fraction of area covered by pods or wands
Arkal	0.089
Flow-Guard[1]	0.033
Lakos	0.071
Waterman Dome	0.124
Waterman Wand	0.316

[1] For the Flow-Guard, the outside diameter of the pod was used to compute the area, rather than the much larger area of the flow distribution cap on top of the pods.

Vertical Distribution of the Slots across the Bottom of the Tanks

No measurements were made of this aspect of uniformity. One can see from the photographs in this report that for some models the pods are at similar elevations; others have substantial variation.

Hydraulic Characteristics

Media tanks were examined individually for hydraulic characteristics. **Figure 3A-17** illustrates the layout for testing with clean water. **Figure 3A-18** is a schematic of water flow when contaminants were introduced.

Figure 3A-17: Schematic of the test setup for test with clean water

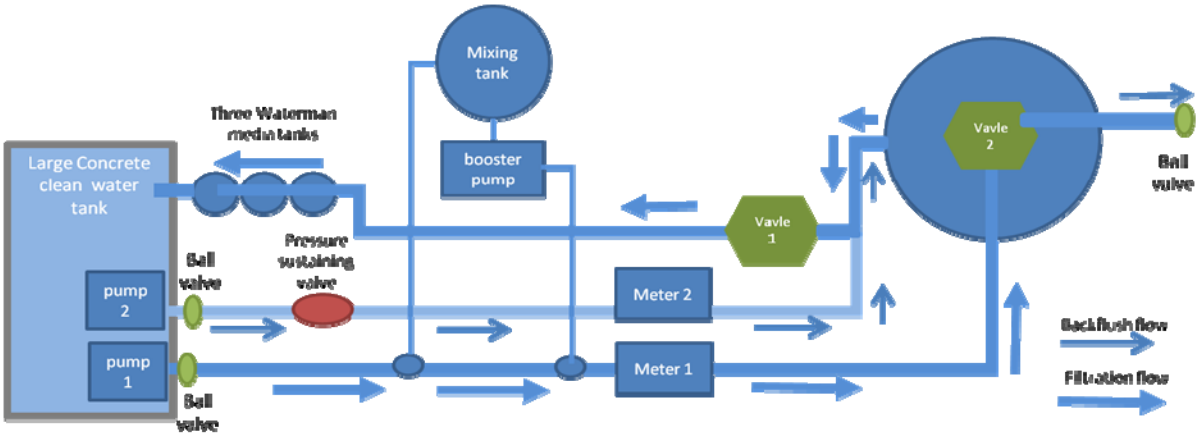
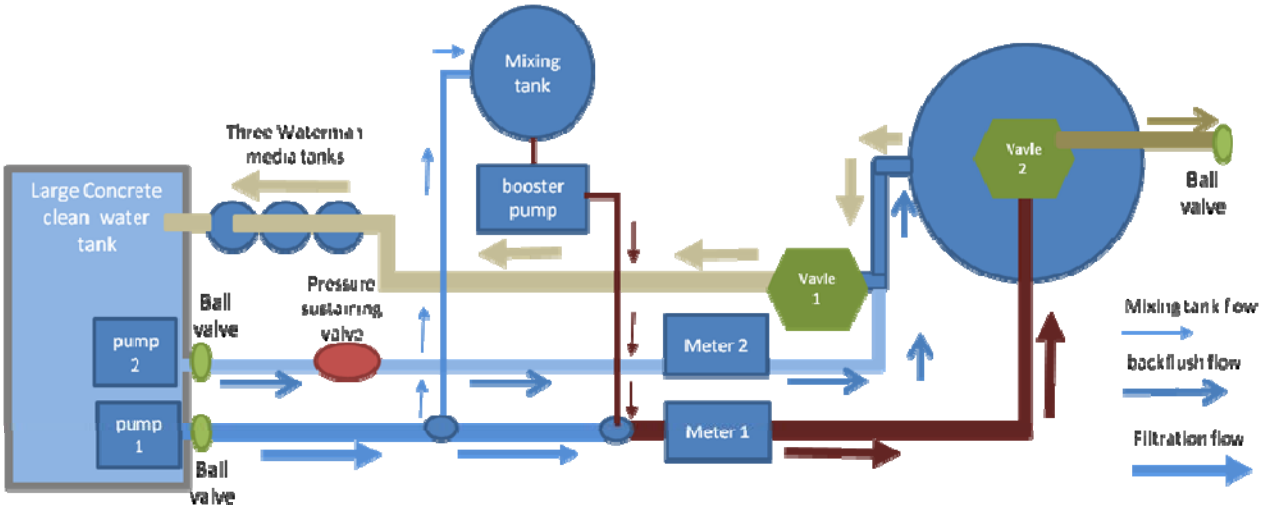


Figure 3A-18: Test layout for dirty water testing



All pressure measurements were pressure differential pressure measurements using a high-quality pressure transducer.

Figure 3A-19: Locations of pressure measurements

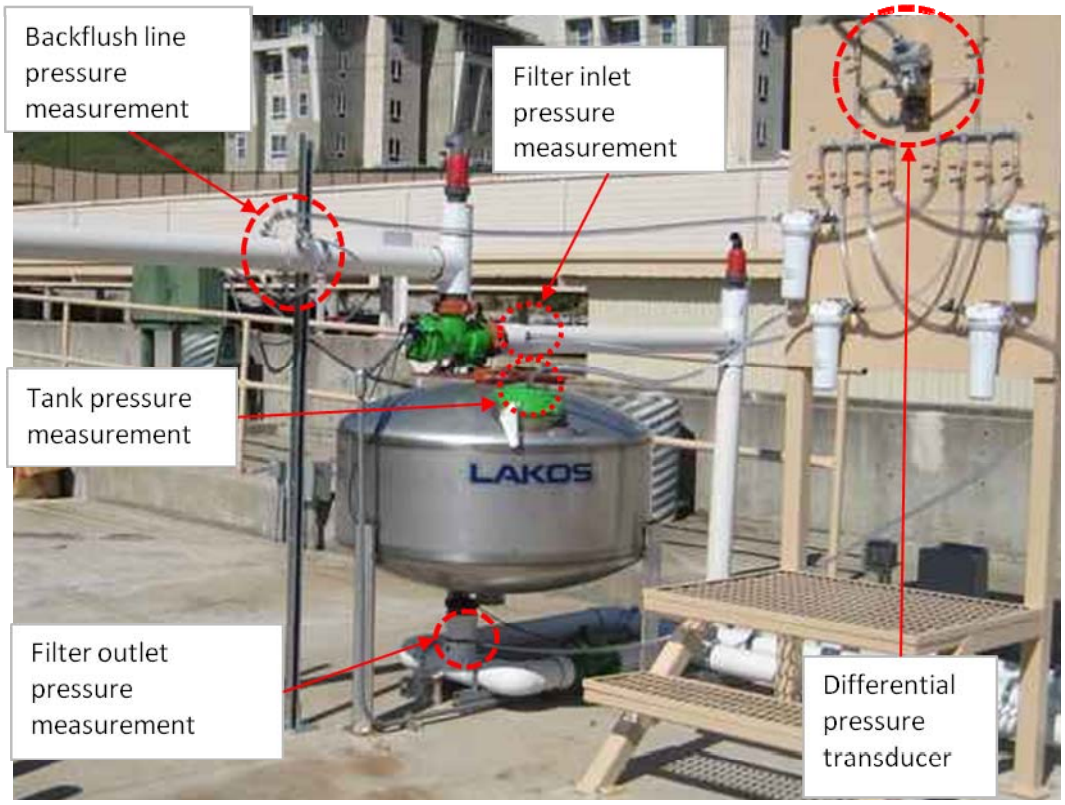


Figure 3A-20: Measurement locations during filtration process

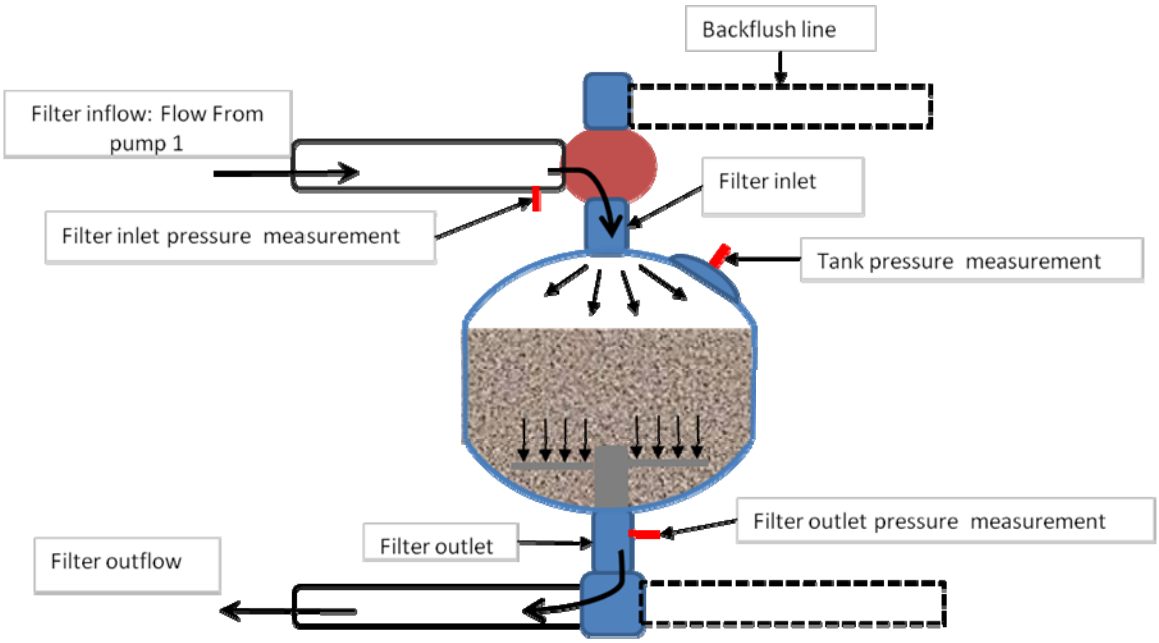


Figure 3A-20 illustrates where pressure measurements were taken during "filtration". The term "filtration" refers to the fact that water is flowing in the direction it would go, if water was being filtered. Only clean water was used for these tests. Because a pressure differential

transducer was used, the "pressure loss" is technically not a "pressure loss" but rather an "energy loss". If single transducers had been used, it would have been necessary to compensate for the elevation differences between the two transducers.

The differential pressure readings were collected as follows:

Total pressure loss = (filter inlet pressure) - (filter outlet pressure)

(Underdrain + Media) pressure loss = (tank pressure) - (filter outlet pressure)

Note: This includes the loss through the media, if it was present

Backflush valve pressure loss = (filter inlet pressure) - (tank pressure)

Figure 3A-21 illustrates where pressure measurements were taken during "backflush". The term "backflush" refers to the fact that water is flowing in the opposite direction as water being filtered. Only clean water was used for these tests.

The differential pressure readings were collected as follows:

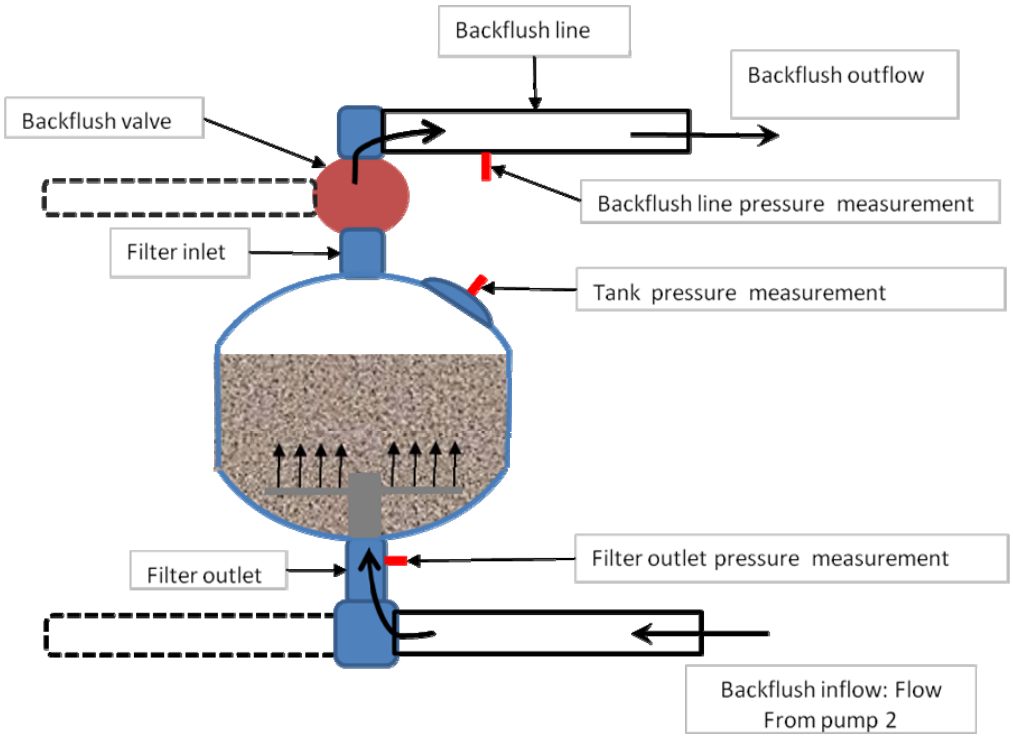
Total pressure loss = (filter outlet pressure) - (backflush line pressure)

(Underdrain + Media) pressure loss = (filter outlet pressure) - (tank pressure)

Note: This includes the loss through the media, if it was present

Backflush valve pressure loss = (tank pressure) - (backflush line pressure)

Figure 3A-21: Measurement locations during backflush process



For the clean water tests for which media was present, the media was cleaned prior to taking measurements, using the following procedure:

1. Start with a clean filter.
2. Fill up with sand media to the manufacturer-recommended level and close fill port.
    a. For the Flow-Guard (FV&C) tank, the gravel was placed first and cleaned with multiple backflush cycles.
    b. The Waterman Wand tank received extra media, as noted earlier.
3. Close flow adjustment valve at Pump 2. Initial flow rate should be much lower than anticipated backflush flow rate (around 100 GPM).
4. Open backflush valve.
5. Start backflush pump (Pump 2).
6. Slowly increase the flow to the set backflush flow rate.
7. Allow pump to run for several minutes.
8. Stop pump and allow system to settle for several minutes.
9. Perform steps 3-8 at least 4 times.
10. Open the port on the filter to view the media in the tank.
11. Fill to the required level again and perform steps 3-8 one more time.
12. Open the port on the filter and view the amount of media in the tank. If it is too low, perform previous steps again until the tank contains the correct amount of clean media.

Media Description

The media was the same as that used locally by irrigation dealers. Descriptive information is:

Manufacturer: P.W. Gillibrand Company, Simi Valley, CA

Size: # 16 crushed silica

Specifications by supplier: Uniformity Coefficient = 1.42; 150-200 mesh filtration

Pressure Losses through the Underdrain (No Media)

The pressure losses through the underdrain were measured at various flow rates and in two different flow directions (**Figures 3A-22 and 3A-23**). The losses are different in the "filtration" vs. "backflush" modes because of the different nature of entrance and entrance conditions around bends and through slots.

Figure 3A-22: Pressure loss in the underdrain during filtration

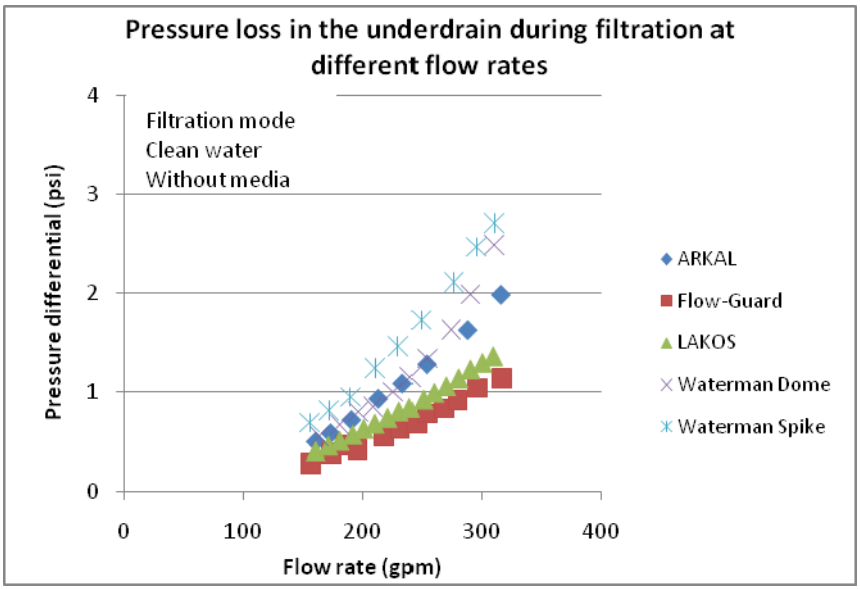
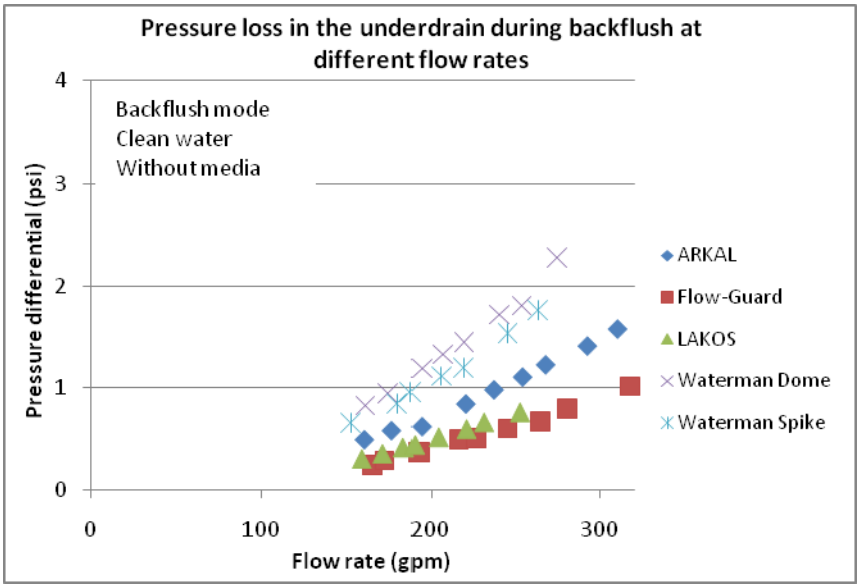


Figure 3A-23: Pressure loss in the underdrain during backflush



Although there are differences between the various tanks, it can be seen that the underdrain loss is relatively minor when compared to the overall pressure requirement of a drip system.

Pressure Loss through the Media

The media loss was computed by finding the difference in (underdrain + media) pressures when the tests were run with and without media. **Figures 3A-24 and 3A-25** show the results. One would think that the loss through the media would be the same regardless of the tank, but there are differences in media height above and below the pods/wands, gravel in one tank, and different flow paths through the media depending upon the pod/wand configurations.

The pressure loss through the media during backflush shows how the loss decreases as the flow increases – due to an expanded (and therefore less restrictive) media bed.

Figure 3A-24: Pressure loss through the media during filtration mode. Clean media and water.

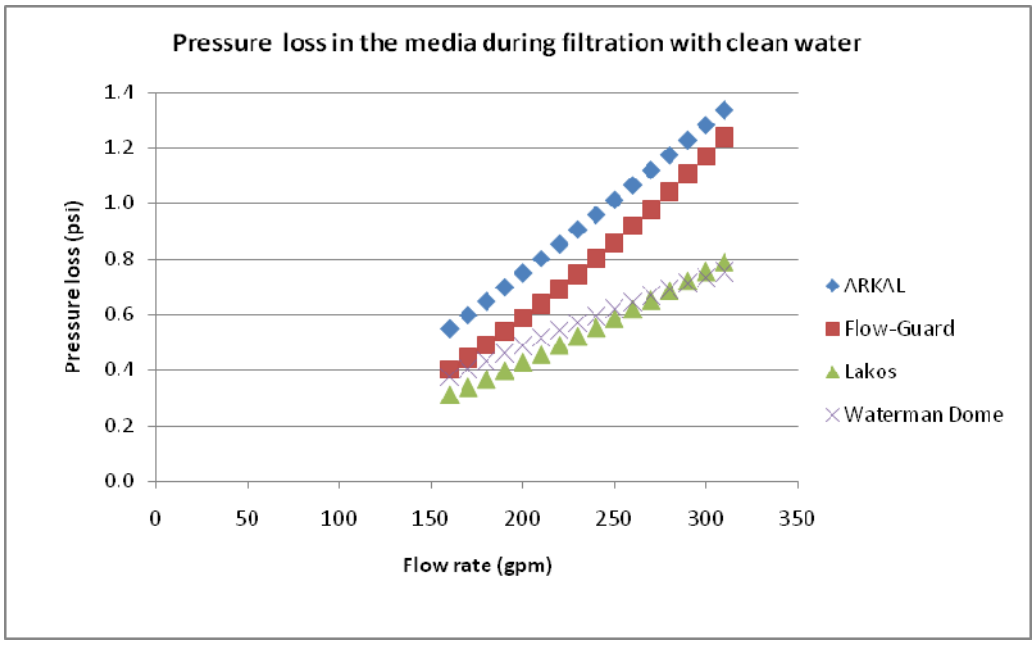
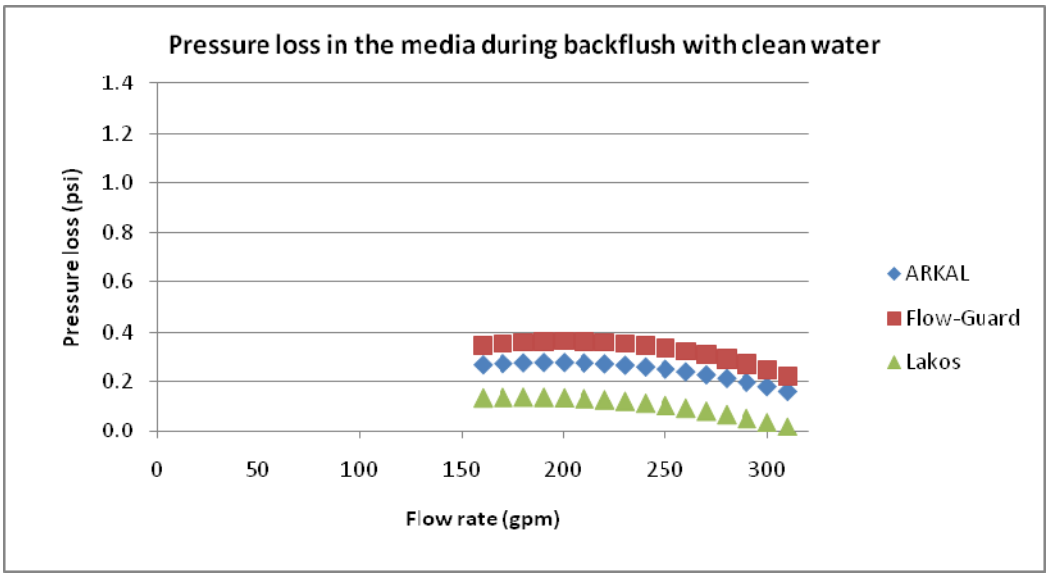


Figure 3A-25: Pressure loss through the media during backflush mode. Clean media and water.



Pressure Loss through the Backflush Valves

The flow path configuration of the backflush valve can be quite different during backflush as compared to filtration. The impact on friction loss is clearly seen when one compares the results in **Figures 3A-26 and 3A-27**.

Figure 3A-26: Friction loss through the backflush valves – filtration mode

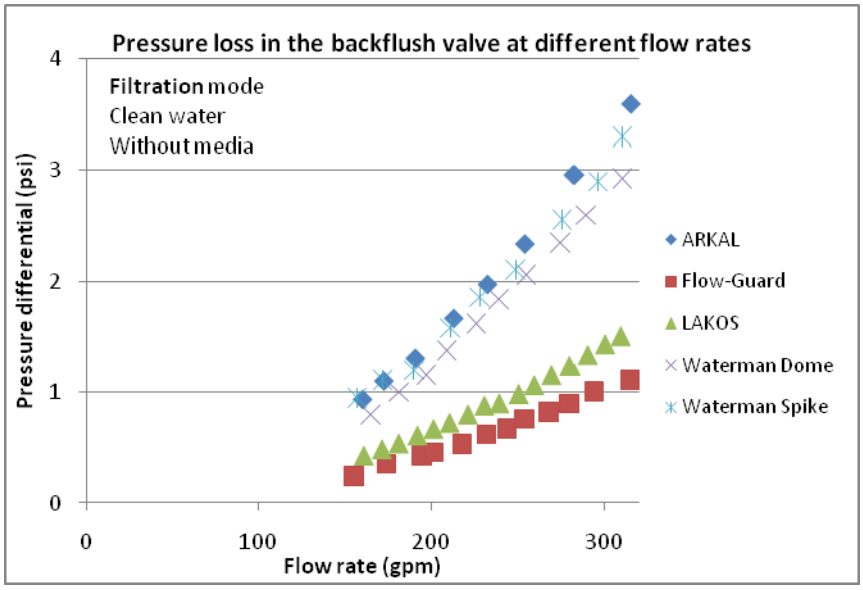
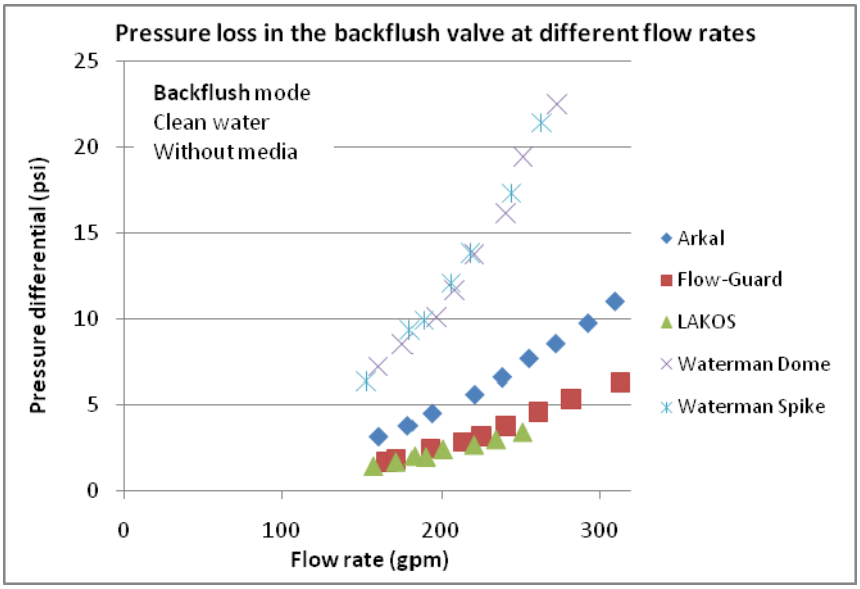


Figure 3A-27: Friction loss through the backflush valves – backflush mode



It is clear that some of the backflush valves have hydraulic characteristics during the backflush mode that require much more pressure for backflushing than other valves. This characteristic dominates the hydraulic pressure requirements for backflushing – when considering only the tank.

Combined Pressure Loss

Figures 3A-28 and 3A-29 show the combined energy loss across the tanks with media.

Figure 3A-28: Total pressure loss across tanks with clean water and media – filtration mode

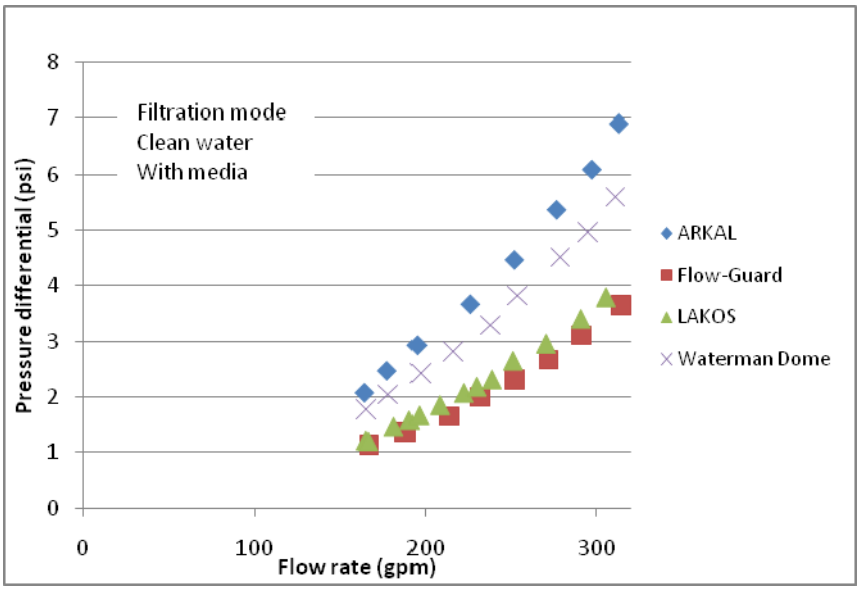
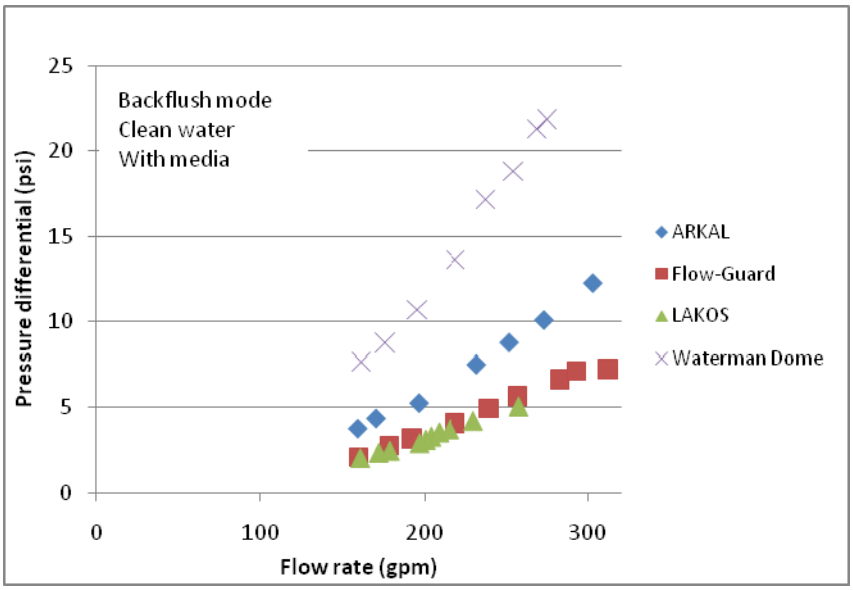


Figure 3A-29: Total pressure loss across tanks with clean water and media – backflush mode



Activation Pressures and Times for Backflush Valves

Backflush valves are "hydraulic" valves and therefore depend on water flow into and out of a chamber that turns the flow on or off in one or more directions. If a backflush valve requires a high pressure to activate, it is possible that this high pressure may exceed all the other drip/micro-irrigation system pressure requirements.

An additional question is how quickly a backflush valve opens and closes. A quick-opening backflush valve will enable the media tank to be cleaned with less water during backflush, because the high flow rate will be quickly established or stopped – without wasting water during the starting and stopping process.

The following physical arrangement was used to test the backflush valve actions. The arrangement put a pressure on both the inlet and "tank" sides of the valve at all times, and also allowed the inlet pressure to remain relatively constant during the on/off action.

Figure 3A-30: Schematic of the test setup with backflush valve closed

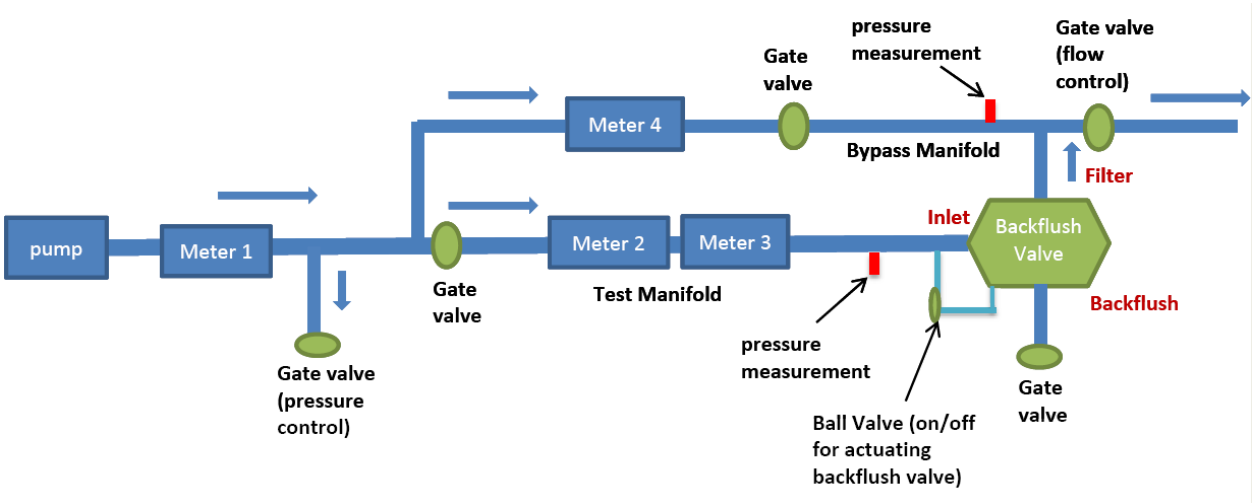
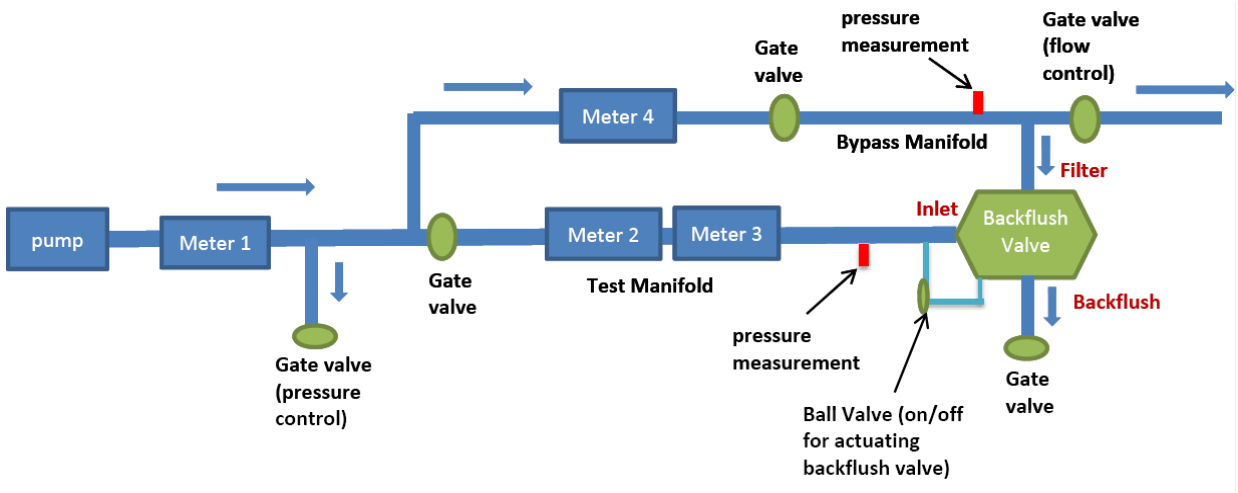


Figure 3A-31: Schematic of the test setup with backflush valve open (actuated)



The test procedure was as follows:

1. Close bypass manifold valve.
2. Adjust flow control valve and pressure control valve for 5 or 6 psi and 250 GPM at the inlet of the test valve.
3. Open bypass manifold valve for 100 GPM through the bypass manifold.
4. Readjust flow control and pressure control valves to reestablish 5 psi and 250 GPM at the inlet of the test valve.
5. Record total flow rate, flow rates through the test and bypass manifolds, and pressure at the inlet and filter outlet of the test valve.
6. Open diaphragm pressure line to actuate the valve.
7. Record the time for the flow rate through the valve inlet to drop to 0 GPM.
8. Record final total flow rate, flow rates through the test and bypass manifolds, and pressure at the inlet and filter outlet of the test valve.
9. Repeat steps 1 – 8 at 6, 7, 8, 9, 10, 15, 20, and 25 psi.

The two Waterman valves were of the same design and brand. The Flow-Guard and Lakos valves appeared to have the same design (with different filter outlet diameters and possibly different manufacturers).

The valve closure time was measured for each of the filter backflush valves at a range of pressures between 5 psi and 25 psi. The Waterman valves actuated the quickest; at 5 psi the valves closed in 6.5 seconds and at 23 psi the valves closed in 4.5 seconds.

The Arkal valve actuated the slowest. The Arkal valve did not begin to close until 13 psi was reached in the inlet line. At 13 psi the valve closed in 25 seconds and at 25 psi the valve closed in 13 seconds. The Flow-Guard and LAKOS valves also closed slowly.

Table 3A-5: Minimum and maximum backflush valve closure times and pressures

Valve	Minimum Pressure (psi)	Valve Closure Time at Min. P. (sec)	Maximum Pressure (psi)	Valve Closure Time at Max. P. (sec)	Average Final Flow (GPM)
Flow-Guard	5	33	23	7	0
LAKOS	6	29	24	9	33
Waterman 1	5	7	22	4	0
Waterman 2	6	6	24	5	0
Arkal	13**	25	25	13	0

*Although the "valve closure time" is measured as the time for the flow through the inlet of the backflush valve to drop from 250 GPM to 0 GPM, for the LAKOS valve there was some leakage through the inlet (ranging from 30 GPM to 38 GPM) after the valve was actuated for each of the pressures tested.

** The Arkal backflush valve did not actuate below 13 psi.

Visual Inspection of the Top of the Media Bed after Backflush

During the initial media cleaning process, the top of the media beds were visually inspected. The intent was to observe obvious uneven (bumpy) surfaces, or distinct color patterns. Such observations indicate uneven backflush flow patterns. The figures below illustrate what was seen.

Figure 3A-32: Arkal AGF-48" media bed after media cleaning

Figure 3A-33: Flow-Guard media bed after media cleaning

Figure 3A-34: Lakos media bed after media cleaning

Figure 3A-35: Waterman Wand ("spikes") bed after media cleaning

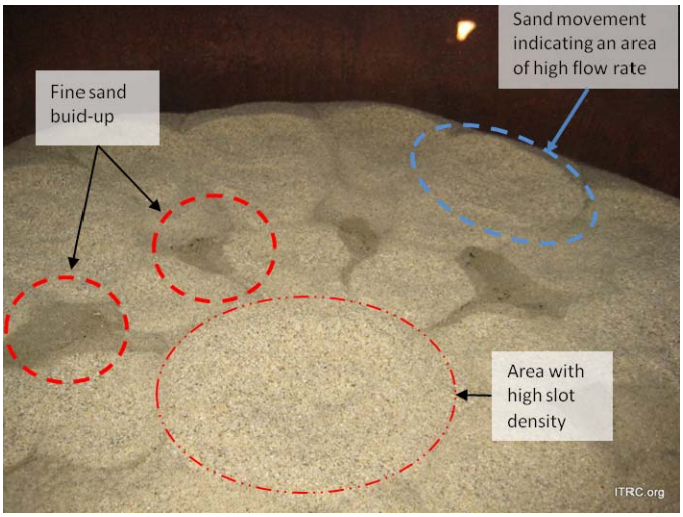


Figure 3A-36: Waterman Dome bed after media cleaning

Discharge of Media during Backflush

A general backflush flow recommendation for a 48" tank is about 190 GPM. Ideally, that would be evenly distributed through the media by the underdrain. If so, the velocities would be identical at all points at the top of the media. The average velocity of the water would be approximately 0.03 ft/sec.

ITRC measured the rate of fall through water of the #16 silica media that was used in tests. Ninety-nine percent of the #16 silica sand used had a settling velocity of greater than 0.12 ft/sec. This means that if the backflush flow rates were evenly distributed, one would not expect any media to be removed during backflushing.

It is common experience in the industry that high-than-recommended backflush flow rates have caused media to be removed. Little more than that general concept is commonly known.

During the media cleaning process, a nylon sock was held over the backflush discharge pipe to collect any media that was removed with a backflush duration of 2 minutes.

Table 3A-6: Sand collected during backflush tests

Filter	Backflush flow rate (GPM)	Mass of sand collected in 2 minutes (gram)
Arkal	200	0
	250	0.2
Flow Guard	200	0.7
	250	48.6
Lakos (new)	200	0.7
	250	18.5
Waterman Dome	200	0.05
	250	2.2
Waterman Wand	200	0.0
	250	0.0

The flow rates in **Table 3A-6** are higher than the 190 GPM or so that is typically recommended. The higher flow rate of 250 GPM was used to examine one aspect of backflush flow uniformity. At the commonly recommended backflush flow rate of 190-200 GPM, all the designs provide little/no media removal.

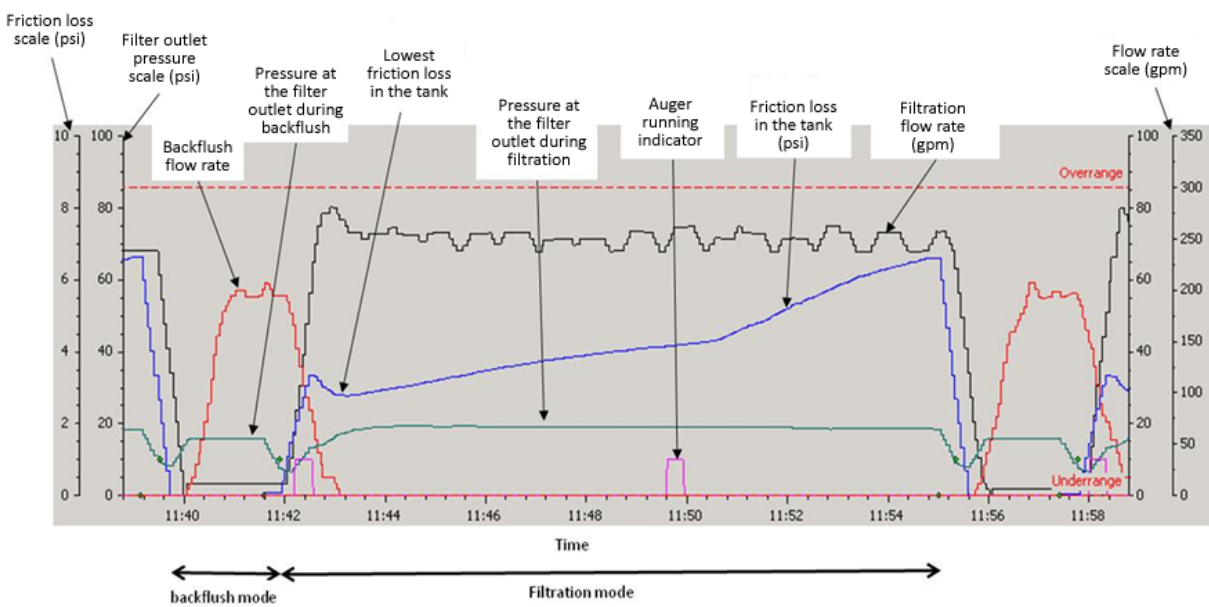
Figure 3A-37: Examples of large amounts of media removed during backflush

Testing with Contaminants

The most complicated and time-consuming aspect of the tank testing involved the injection of a combination of organic and inorganic materials into water that subsequently passed through the filter tanks. Because of the complexity and difficulties, only two tanks were tested – the Flow-Guard and Lakos tanks.

The filter backflush was controlled to start when the differential pressure was 4 psi greater than the clean total differential pressure at 250 GPM. Pressures and flows were continuously recorded. **Figure 3A-38** illustrates a typical set of data.

Figure 3A-38: Example data collected during filtration with contaminant



Contaminant Description

A combination of soil and organic matter was used. The soil was collected from the bottom of an irrigation canal near Corcoran, California at the JG Boswell Farm, which has a high percentage of silt. The soil was separated into 5 piles, one bucket at a time, to ensure the creation of 5 similar treatment piles (although only 2 were eventually used).

The organic matter was ground manure from the Cal Poly compost facility. Contaminants were injected for 15 days, 8 hours/day.

Table 3A-7: Contaminants injected during 15-day tests

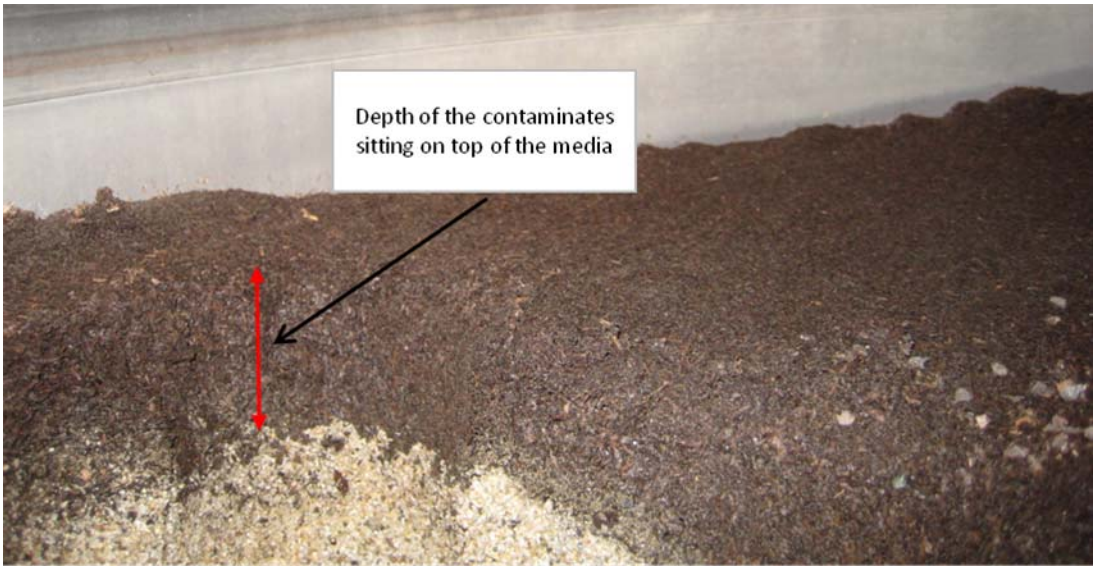
	Lakos	Flow-Guard
Pounds of soil injected	432	432
Pounds of manure injected	264	264
Volume of water filtered (gallons)	1,501,700	1,543,100
Avg. ppm of contaminants	51	46

The first attempts at introducing organic matter utilized several potting soils that were purchased at Home Depot. There were two major problems that were immediately encountered:

1. The potting soil appeared to catch on the inlet dissipater in the Lakos unit (see **Figure 3A-39**).
2. The potting soil layered the top of the media and built up, and was not removed with backflushing (see **Figure 3A-40**).

Figure 3A-39: Potting soil caught on inlet dissipation screen of the Lakos media tank. Flow-Guard has a similar dissipation screen, but was not tested with potting soil.

Figure 3A-40: Potting soil that accumulated on the top of the media bed, even after repeated backflushing



The experience with potting soil clearly demonstrated the need for having adequate pre-filtration of water before it enters media tanks.

The weakest aspect of the contaminant testing was that the dirt injection mechanism was not continuous. Rather, an auger was activated over a 20-second period once every 7 minutes. The soil/manure mix was augured into a container that mixed it with water, and the mixture was subsequently pumped into the main supply pipe. The result was an injection of contaminants into the supply water for about 1 minute every 7 minutes. This certainly does not match standard injection conditions, although quite frequently media filters are subjected to bursts of contaminants.

In spite of this injection problem, the injection was consistent over the tests and consistent between the two tanks that were tested. Therefore, the results of the two tank tests are comparable. ITRC does not know if the results are completely realistic.

Backflushing of Contaminants

ITRC does not propose some new term such as "filtration efficiency" or "filtration effectiveness". It can be stated that measurement of the discharge water quality for solids, during filtration, was inconclusive. That means that both the Flow-Guard and the Lakos filters were removing the solids. In that sense, they might well be considered to be very "efficient".

The more challenging equation with media tank testing is to determine if the contaminants, once captured in the media, are removed during backflushing. Two measurements that might indicate the effectiveness of contaminant removal during backflushing include:

1. Do backflushing events become more frequent over time?
2. Can accumulated contaminants be measured throughout the media after the testing?

<u>Frequency of backflushing.</u> The two figures below show 17 days, although the time period of interest is 15 days. Some additional tests were run on the last 2 days.

Figure 3A-41: Number of backflushes per day – Lakos

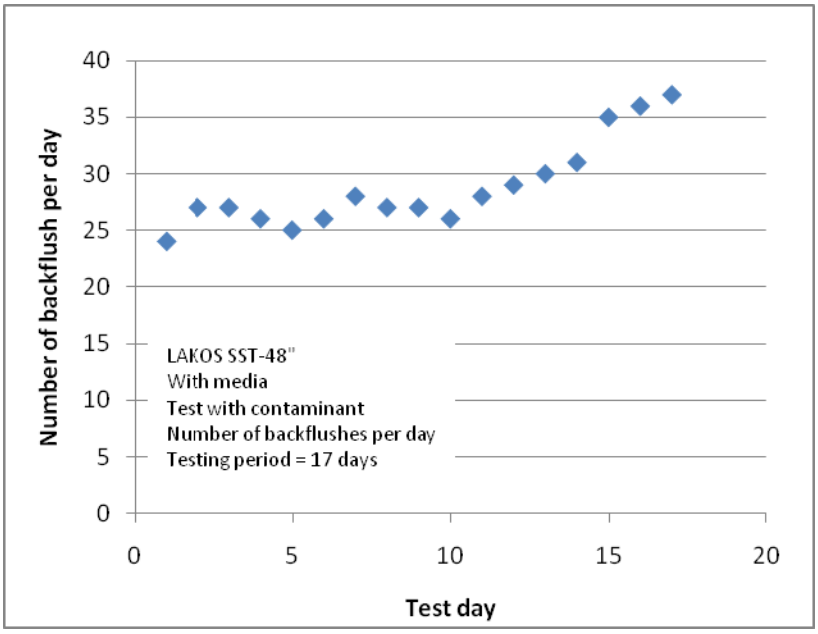
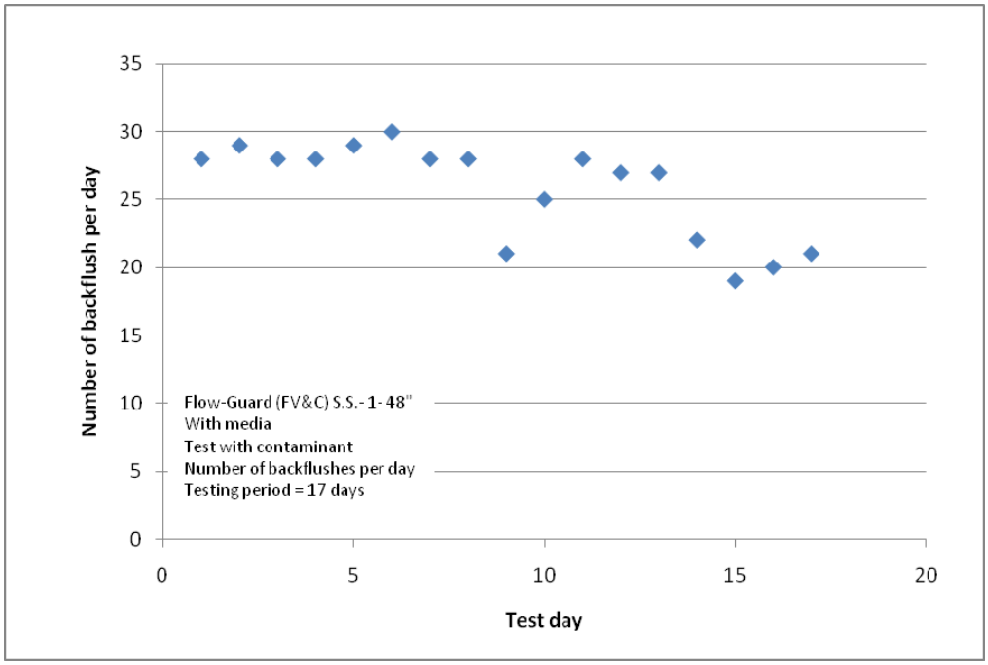


Figure 3A-42: Number of backflushes per day – Flow-Guard



No measurements or observations conclusively showed why the trends are so different for the Lakos versus the Flow-Guard. In particular, it seems unusual that the Flow-Guard would backflush less often over time.

Contaminant Retained in the Media

After the extended injection of contaminants, samples of the media were collected in a pattern defined by a template, as shown in Figure 3A-43.

Figure 3A-43: Plastic template used to position sampling cores across the top of the media

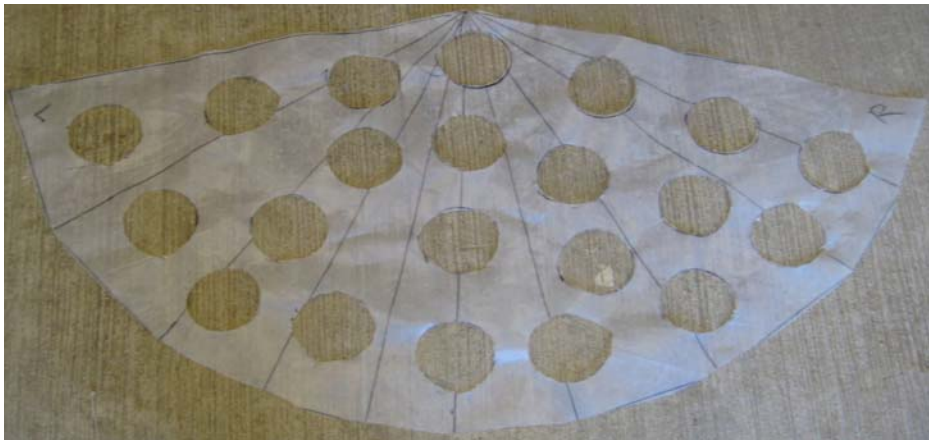


Figure 3A-44: PVC cores forced 4" deep into each hole in the template, with collected soil

The media collection process was:

1. At the end of the test with contaminant (17 days) if the process ended in the middle of filtration mode, the backflush mode was run to make sure that all the tanks were in the same situation at the end of the test.
2. The tank was drained.
3. With the media inside still wet, the plastic sampling location layout was placed in the tank.

4. In each location a 3″ PVC pipe was pushed four inches deep into the media.
5. The media and contaminants inside the PVC tube were collected.
6. The media collected in PVC cylinders was divided into two parts:
    a. Small sample at the bottom of the cylinder, where there are no large contaminant particles
    b. Large sample from the surface (the upper part of the sample), where there are large particles

The contaminants were separated from the media and tabulated as a percentage by weight for each sample. Table 3A-8 gives the results for the two tanks that were tested.

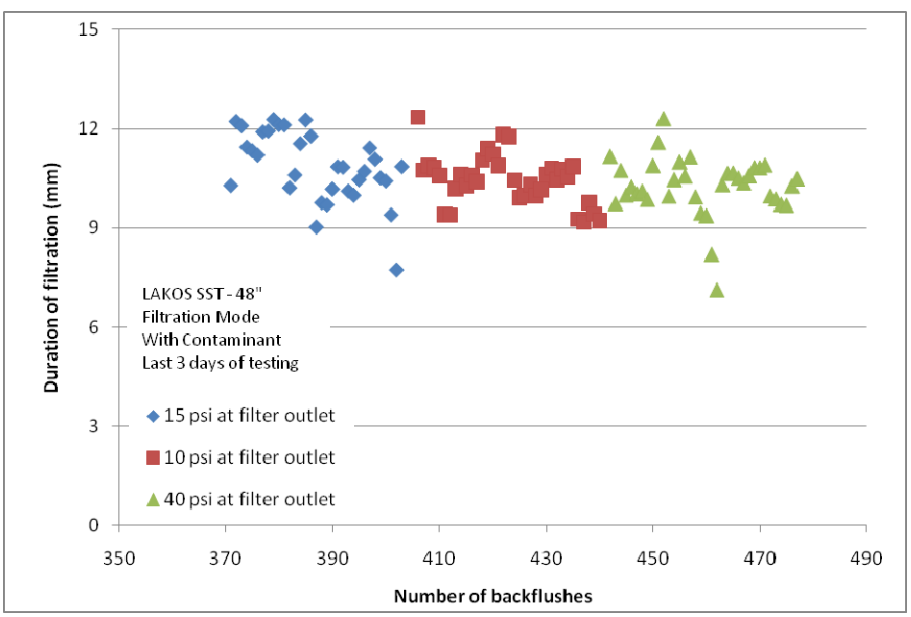
Table 3A-8: Contaminant analysis from sand media

	Top layer			Bottom layer		
Filter	Percentage of Non-media	Standard deviation, %	cv	Percentage of Non-media	Standard deviation, %	cv
Flow-Guard	4.9	4.3	0.9	1.0	0.4	0.4
Lakos	12.0	3.9	0.3	3.1	2.6	0.8

Backflush Pressure versus Flow Rate

The backflush action of a media filter is dependent upon the backflush flow, not on the backflush pressure. Figure 3A-45 shows that the pressure at the bottom of a filter does not impact the backflush – as long as the flow rate is the same. For all three bottom pressures, the backflush flow rate was the same.

Figure 3A-45: Duration of filtration compared to number of backflushes, showing that the pressure at the bottom of the filter does not impact dirt removal, if the flow rate remains constant



Summarized Observations

Most of the key physical characteristics are summarized below. In Table 3A-9, the best values for each category are highlighted in blue; the lowest are highlighted in purple. The "Relative Importance" values are a very first attempt to designate which characteristics are more important than others. For example, a filter may receive a low rating for a characteristic that is not very important. Also, the various characteristics are not independent. For example, the amount of sand removal during backflush is highly dependent upon the design of the underdrain.

The reader should be aware that the specific values are not as important as the relative values. For example, if 40 grams of sand is removed during backflush, it is not really important if it was 45 or 35—if other units had almost no sand removal.

It is also clear that there are always some inaccuracies in measurement and small differences are not significant. A value of 0.8 psi friction for the Flow-Guard, and 0.9 psi for the Lakos valve were considered to be the same value by ITRC. Hence, both valves were given the same rating for that characteristic.

Table 3A-9: Characteristics of the media filter tanks

Feature	Characteristic	Measured Values for Different Tanks						Relative Importance*
		Arkal	Flow-Guard	Lakos	Lakos New	Waterman Wand	Waterman Dome	
Valve	Friction during filtration with #16 silica media @250 GPM, psi	2.3	0.8	0.9		2.2	2.1	2.5
	Friction during backflush with #16 silica media @200 GPM, psi	5.0	3.0	2.8		11.5	11.5	5
	Pressure required to open, psi	13.0	5.0	6.0		5.0	6.0	5
	Valve closure time at 22-25 psi, sec.	13.0	7.0	9.0		4.0	5.0	6
System	Total friction loss during filtration @250 GPM when clean	4.3	2.2	2.5			3.6	3
	Total friction loss during filtration @200 GPM when clean	6.0	3.5	3.0			13.0	5
Sand Removal	Mass of sand (grams) in 2 minutes @250 GPM	0.2	48.6		18.5	0.0	2.2	10
	Mass of sand (grams) in 2 minutes @200 GPM	0.0	0.7		0.7	0.0	0.1	
Underdrain	Horizontal area (sq. cm.) served by each pod or wand unit	214	613	446		117	214	6
	Coefficient of variation of the horizontal area served per pod/wand unit	0.24	0.14	0.31		0.75	0.17	8
	% of the horizontal area that is covered by pods or wands	9	3	7		32	12	8
	Mean slot width, mm.	0.33	0.23		0.27	0.19	0.29	
	Std. Deviation of slot widths, mm.	0.036	0.029		0.036	0.026	Not meas.	5
	Total slot open area, sq. Cm.	200	184		261	343	108	5
Summary	**Total best ratings**	1	7	5		8	4	
	Total worst ratings	6	3	1		3	4	

*The greater the Relative Importance value, the more important this characteristic is.

What is apparent from Table 3A-9 is that none of the units was consistently the best or the worst. Each had advantages and disadvantages.

Some summary points are:

1. Some manufacturers have backflush valves with small flow passageways that require a high backflush pressure to achieve a recommended backflush flow rate.
2. Some manufacturers have backflush valves that have very little pressure loss during backflushing.
3. Although there are differences in friction loss through the media and through the underdrains of various manufacturers, this component of pressure loss is minor compared to the losses through some backflush valves.
4. Some backflush valves require high pressures to physically function properly.
5. This study found no good evidence that high pressures are needed for obtaining good backflushing of media filters if large backflush valves are used.
6. There are significant differences between models/manufacturers regarding many aspects of the underdrain designs, including:
    a. Total open area of slots
    b. Uniformity of slot widths
    c. Percentage area of the horizontal area of a tank that is occupied by pods/wands
    d. Uniformity of pod/wand placement horizontally
    e. Uniformity of pond/wand placement vertically
7. A visual inspection of the tops of media beds after backflushing showed that there was non-uniform backflushing by all tanks.
8. A very uniform backflush through #16 silica media should cause almost no removal of media at 190 GPM, because the settling velocity of the media is about 4 times greater than the upward velocity of the water. The amount of backflushed media at a relatively high backflush rate (250 GPM) gives one simple and clear indication of the uniformity of backflush – or at least of the existence of some localized zones with very high velocities.
9. The partial plugging of the inlet flow dissipaters, and the lack of removal of bark-like contaminant during backflush, are clear indicators of the importance of adequate pre-filtration upstream of media tanks.

Energy Implications

1. Common industry opinion is that media tanks require at least 30-40 psi to operate properly. This is a significantly higher pressure than what is required for most row crop drip (i.e., tape) irrigation systems. Many row crop drip systems can be designed to operate at about 20 psi, not including the filter pressure requirements. In other words, a 30-40 psi requirement for filtration will determine the pump discharge pressure requirement.

2. The research presented in this report indicate that backflush valves (during the backflush mode) can be the major cause of a pressure drop during backflushing. Therefore, the following guidelines are recommended for the backflush valves of 48" media tanks:

    a. Backflush valves should have no more than 5 psi loss during backflushing at 200 GPM

    b. Backflush valves should require no more than 6 psi to operate properly – in other words, to securely seat in the backflush position with no leakage. If more pressure is required, that pressure should be supplied by a different pressure supply – one that is only actuated during backflush for the small flow rates needed to activate the valves.

    c. Backflush valves should activate in both directions in less than 4 seconds at 25 psi, and in no more than 8 seconds at 15 psi.

3. It is common lore in the irrigation industry that a high pressure is needed for backflushing if the media beds plug up. It appears from this research, although it is not proven, that a non-uniform backflush flow through the media tank can cause much of the media to be ineffective. Therefore, it is hypothesized that a very uniform backflush will reduce problems with plugging up of the media beds. Continuing with this logic, if the media beds do not plug up, there is no need for a high pressure "on standby" to unplug a dirty media bed.

4. A uniform backflush of the media bed will provide better cleaning of the media and less gradual buildup of contaminant in poorly fluidized zones. More uniform backflushing should eventually result in less backflush volume per volume of water filtered, which in turn saves the energy associated with pumping that extra backflush water.

5. To minimize the pressure needed for backflushing, designers and installers must consider at least three other points. Prior experience by ITRC points to these common problems:

    a. The backflush water disposal pipelines may be poorly designed and restrict the backflush flow. Typical errors include not using large enough diameters, having long pipelines, and not including adequate air release valves in the backflush pipeline.

b. The backflush timing and flows (frequency, duration, flow rate) may be improperly adjusted. This can result in a “caking up” or “plugging up” of the media that requires either mechanical agitation or a very high pressure to break up.

c. Only two tanks are used. If only two tanks are used, the friction loss through the one functional tank (i.e., the tank that must filter the backflush water for the other tank, plus supply the irrigation system) can easily be 3-4 times the normal operating friction loss. Assuming that the tanks are set to backflush at a 6 psi differential, this means that during backflush the one flowing tank may have an 18-24 psi friction loss across it.

APPENDIX 3B:
Characterization of Pumps for Irrigation in Central California: Potential Energy Savings

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INTRODUCTION

The annual agricultural electric pumping usage in California is around 10 million MWh and most of it occurs in the Sacramento and San Joaquin Valleys, where the majority of agriculture is located (Burt et al., 2003).

Pumping costs are often higher than they should be for two reasons: more water is pumped than is necessary, and/or the pumping plant operates inefficiently (either the pump itself is inefficient, or the total dynamic head is greater than needed).

Ideally, new electric overall pumping plant efficiencies (OPPE) should be at least 70 percent (for greater than 25 kilowatts) and every new pumping plant should be tested to verify/determine the starting OPPE. Current practices in the California agricultural irrigation market do not typically guarantee a new OPPE, nor are verification tests performed by the pump vendor or others.

Pumps that are initially efficient can become inefficient through pump wear, changes in groundwater conditions, and changes in the irrigation system (Hanson, 1988). Options for improving OPPE include adjusting impellers, repairing or replacing worn pumps, replacing mismatched pumps, and converting to energy efficient electric motors (Hanson, 2002). Variable frequency drives, while not improving the OPPE, reduce the input kW by only producing the flow and pressure combination that is required at the moment.

Pumping plants should be evaluated every several years to determine the status of the pump and possible reasons for poor efficiency. Evaluating a pumping plant requires a pump test, during which capacity (flow rate), lift, discharge pressure and input horsepower are measured. Electric utilities such as Pacific Gas and Electric Company have provided such evaluations for over 70 years in California to minimize energy consumption in the irrigation sector. Additional programs have been sponsored by the California Energy Commission (Burt and Howes, 2005).

Though pump repair or replacement can substantially improve performance, energy savings will also depend on management and the design of the irrigation system. To reduce electrical energy use, the kilowatt-hours must decrease because of fewer kilowatts (kW) or less operating time, or both. If the new/repaired pump produces a higher flow rate than before, the hours of operation must be reduced to deliver the same volume; operating the same number of hours can use just as much electricity as before.

Irrigation pumps are typically overdesigned to cope with the worst working conditions (normally peak demands, and low groundwater levels) but this means that in normal operation

the pump will use more kW than necessary for a desired flow rate. In such cases, installing variable frequency drives (VFDs) allows pumps to run at slower speeds in cases of lower demand (pressure or flow rate), requiring less kW – even though the impeller/bowl efficiency may be lower than at the maximum design flow rate and pressure. High efficiency motors should save 3-5% of their operating cost, although some motors labeled as being "high efficiency" appear to have lower efficiency than standard motors (Burt et al. 2008).

The points above are well known in concept. However, information from large datasets of actual pump performance is difficult to obtain. This paper describes an analysis of over 15,000 electric irrigation pump tests in Central California.

OBJECTIVES

The analysis of the pump tests had the following objectives:

- Define the common characteristics attributed to pumps with best and worst performance and energy consumption.
- Identify the possible target groups that might benefit from improvements, to obtain better efficiencies and reduce energy consumption.
- Obtain rules for targeting pumps for testing, to achieve the maximum energy savings per number of pumps tested.
- Estimate the potential energy reduction if various groups of pumps are targeted.

METHODOLOGY

A database of irrigation pump test information was compiled from a variety of sources. Data were from the Salinas, Sacramento and San Joaquin Valleys of California over a 5-year period ending in 2009. Data from two different types of pumps were used: well and non-well (mainly booster pumps). No information was available regarding entrance conditions, well pump column losses, or excess pressure requirements of irrigation systems. Pumps were tested by small independent firms that specialize in pump testing.

The reported well pump OPPE values are lower than an OPPE that might be estimated by only considering the impeller/bowl efficiency and motor efficiency. This is because the Total Dynamic Head (pressure) was estimated to be the sum of only the elevation change (discharge elevation minus the pumping water level) plus the discharge pressure. Column losses, entrance screen losses, and discharge head losses were ignored by the pump testers. Furthermore, the shaft horsepower requirements to overcome shaft bearing losses and thrust bearing losses were not included.

The variables available for comparison included:

- Total dynamic head (TDH, m): The sum of the pumping lift and the discharge head for vertical pumps; discharge minus inlet pressure for booster pumps.
- Measured Flow Rate (Q, l/s)
- Input power to the motor (kW)
- Drawdown (Drdw, m): difference between the pumping water level and the standing water level (only in well pumps)

- Discharge pressure (DPres, bar): pressure on the outlet side of the pump
- Kilowatt-hours per unit volume (kWh/m^3): kilowatt-hours required to pump a cubic meter of water at the operating condition measured
- Annual energy consumption (MWh/y): Megawatt-hours consumed per year (only available for some pumps). 1 MWh = 1000 kWh
- Overall Pumping Plant Efficiency (OPPE, %): water power generated by the pump (function of the flow rate and reported total dynamic head) divided by input power

Data for 12,887 well pumps (902 in Salinas, 497 in Sacramento and 11,488 in San Joaquin Valley) and 2,875 non-well pumps (295 in Salinas, 248 in Sacramento and 2,332 in San Joaquin Valley) were used. Within this dataset, values for annual energy consumption were available for 5,436 well pumps and 896 non-well pumps.

A multivariate cluster variable analysis was performed with Minitab® 16.1.0 to study the variables' similarity level. In addition, the different variables were compared to each other in order to find correlations and significant trends in the data. Scattered plots were used with function adjustment.

To study the potential energy savings associated with pumps of different characteristics, different groupings were made according to the annual energy consumed, and TDH and Q ranges. With this grouping, comparisons between pumps working at similar conditions are possible. Averages for all the variables were calculated for each group. Pumps with an OPPE below the group average are considered to be potentially improved. The energy saved in these pumps is estimated as the difference between actual energy consumption and the average of the top 25% of the pump efficiencies within that group.

For example:

Pump with OPPE = 36%
Energy consumption = 398 MWh/year
The OPPE average of best 25% performers of the group = 68%

Therefore, the energy savings are estimated as follows, assuming the new pump is operated at the original flow rate and TDH:

$$\text{New Energy Consumption if "average"} = \frac{Old\ OPPE}{New\ OPPE} \times Present\ energy\ consumption$$

$$= \frac{36\%}{68\%} \times 398\ MWh/yr = 211\ \text{MWh/yr}$$

$$\text{Savings} = \text{Original energy consumption} - \text{New energy consumption}$$

$$= 398\ \text{MWh/yr} - 211\ \text{MWh/yr} = 187\ \text{MWh/yr}$$

In that way, the total and average potential energy savings are calculated for each group – without considering additional savings that would be possible if the TDH was reduced. An average price for energy of $0.15 per kW was used to obtain the possible money savings in each case.

RESULTS

Overview facts

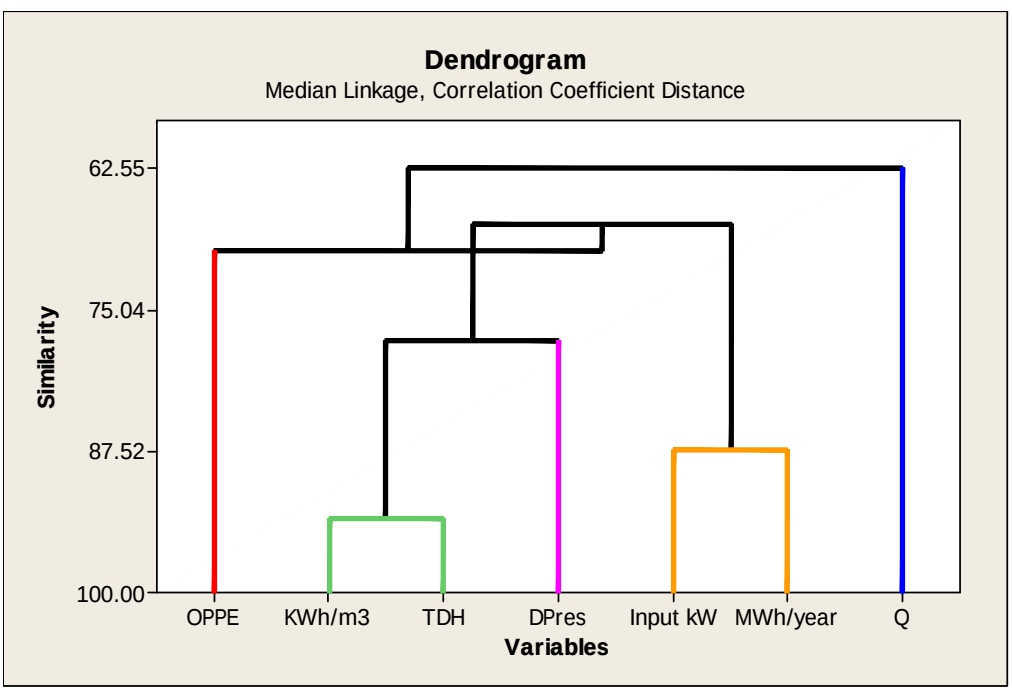
The OPPE average value is 53% for well pumps and 52% for non-well pumps. This means that the actual OPPE for well pumps is somewhat higher than for non-well pumps if the various bearing, column loss, and other items were considered. These values are similar to those of Burt and Howes (2005 and 2008) where average OPPE values for pumping plants in California were 57.5% and 55% respectively. Thirty-five percent of well pumps and 51% of non-well pumps have poor OPPEs (lower than 50%). Only 6% of well pumps and 9% of non-well have OPPEs over 70%.

The total annual energy consumption of the studied pumps is estimated at 724,083 MWh (641,720 MWh for well and 82,363 MWh for non-well pumps) with an average of 118 MWh/year for a well pump and 92 MWh/year for non-well pumps. The average energy consumption per volume of water pumped in the case of well pumps (0.33 kWh/m^3) is twice that of non-well pumps (0.16 kWh/m^3).

Correlations between variables (all pumps)

A hierarchical cluster analysis was performed using Minitab® 16.1.0 to study the similarity between variables. The dendrogram shown in Figure 3B-1 is a graphical representation of its results. In this tree-like plot each step of hierarchical clustering is represented as a fusion of two branches which represent the clusters obtained according to the level of similarity found in the variables' values. This analysis showed that TDH and kWh/m^3 were highly similar. Also, input power and the energy consumption in a year had an analogous behavior. On the other hand, OPPE and Q are more independent variables. This information is useful to reduce the number of variables in order to continue with an analysis. Therefore, OPPE, TDH, Q and MWh/year were selected as key variables.

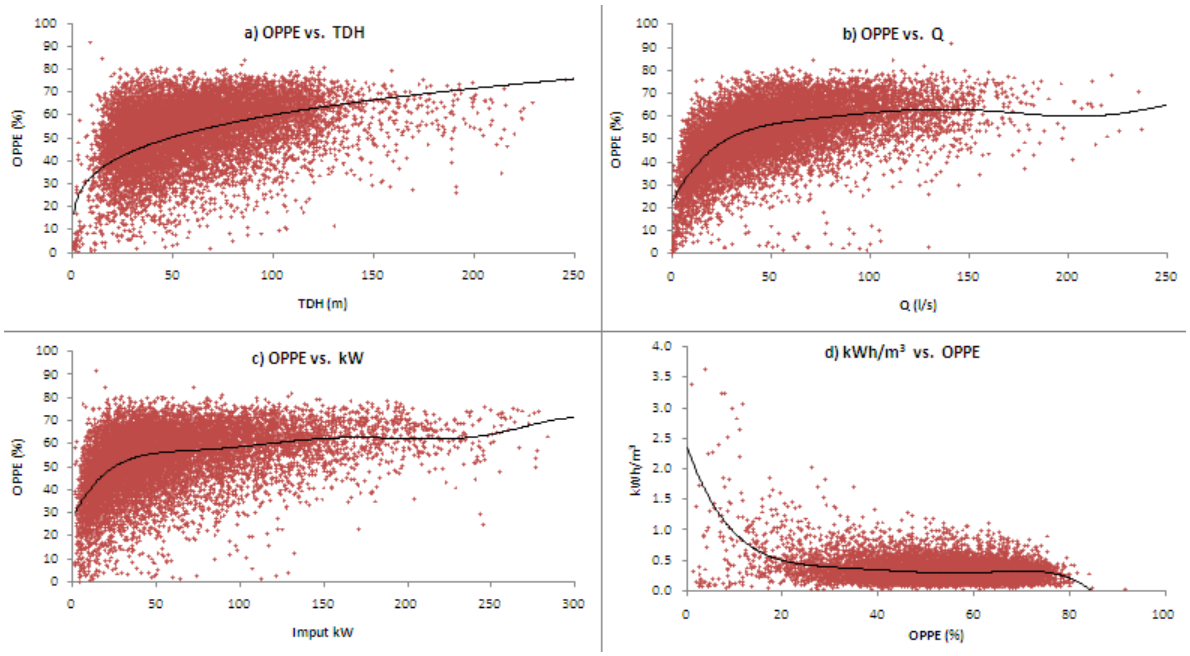
Figure 3B-1: Dendrogram showing similarity between variables



Trends and correlations between variables (well pumps)

OPPE values tended to be better when TDH, Q and input power are high. This pattern is clearer in the case of TDH where 85% of pumps with OPPE < 50% have a TDH < 75 m while 70% of pumps with OPPE < 30% have a TDH < 45 m (Figure 3B-2a). When TDH > 120 m, only 16% of pumps have an OPPE under 50%.

Figure 3B-2: Correlations for well pumps, OPPE (%) vs. other variables: a) TDH (m); b) Q (l/s); c) input power (kW); d) kWh/m^3



When looking into the relation between OPPE and Q (Figure 3B-2b), small flow rates are frequently associated with lower OPPEs. In fact, 75% of pumps with OPPE < 50% have a Q < 50 l/s while 80% of pumps with OPPE < 30% have a flow rate under 25 l/s. Only 11% of high flow pumps (over 125 l/s) have OPPEs below 50%. It is observed that when Q is high, even when TDH values are low, OPPE values are better.

Once again, low values for the input power are related to poor OPPEs (Figure 3B-2c): 76% of pumps with OPPEs < 50% have an input power below 50 kW and only 9% of pumps with more than 150 kW show an OPPE under 50%. High values of kWh/m^3 are related with low OPPE (all the pumps consuming more than 1.2 kWh/m^3 have OPPE below 50%, but no trend is observed for pumps with less than 0.1 kWh/m^3 (Figure 3B-2d). Nevertheless, pumps with very high efficiency show lower consumption per volume pumped. Increasing trends are not so clear for OPPE vs. drawdown and discharge pressure.

Obvious increasing trends are observed when relating annual energy consumption (MWh/year) with TDH, Q and kWh/m^3 (Figure 3B-3). However, high values of energy consumption occur in certain intervals (75-150 m for TDH; 100-125 l/s for Q, and 0.3-0.6 kWh/m^3). This situation can be better observed in the contour plot provided (Figure 3B-4). Therefore, bigger pumps lifting more flow with high TDH do not necessarily consume more energy during the year as they are not usually operating so many hours.

Figure 3B-3: Correlations for well pumps, energy consumption (MWh/year) vs. other variables: a) TDH (m); b) Q (l/s); c) input power per volume pumped (kWh/m^3); d) OPPE (%)

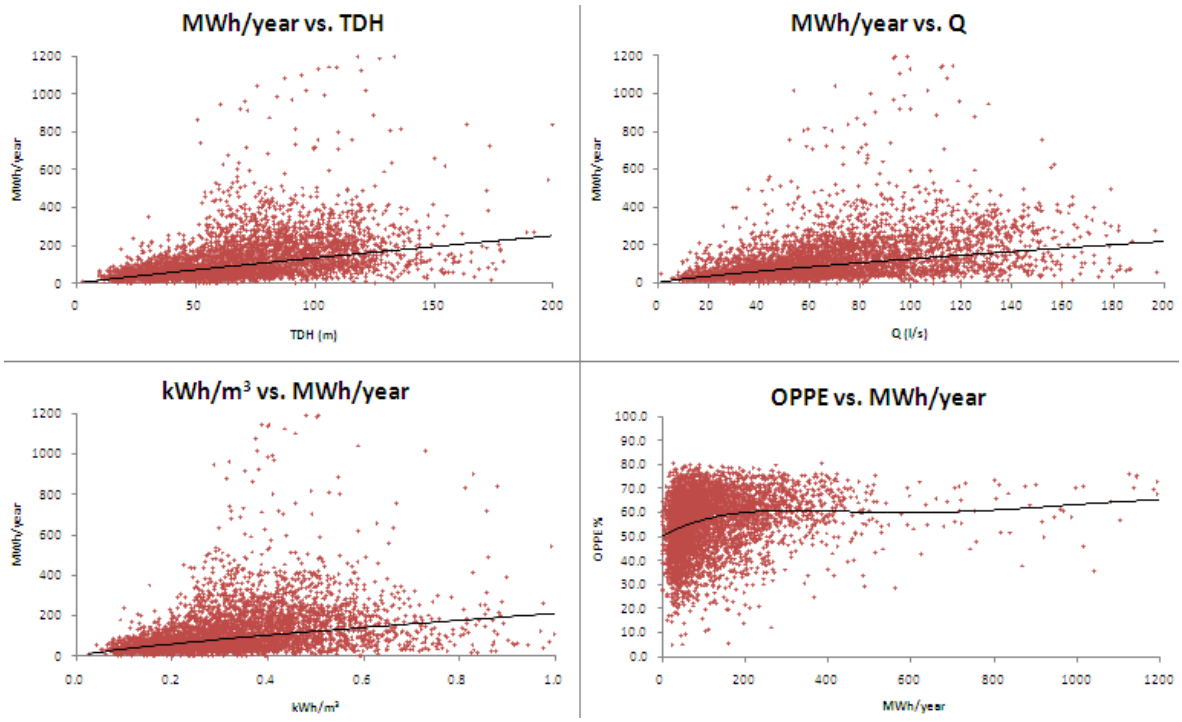
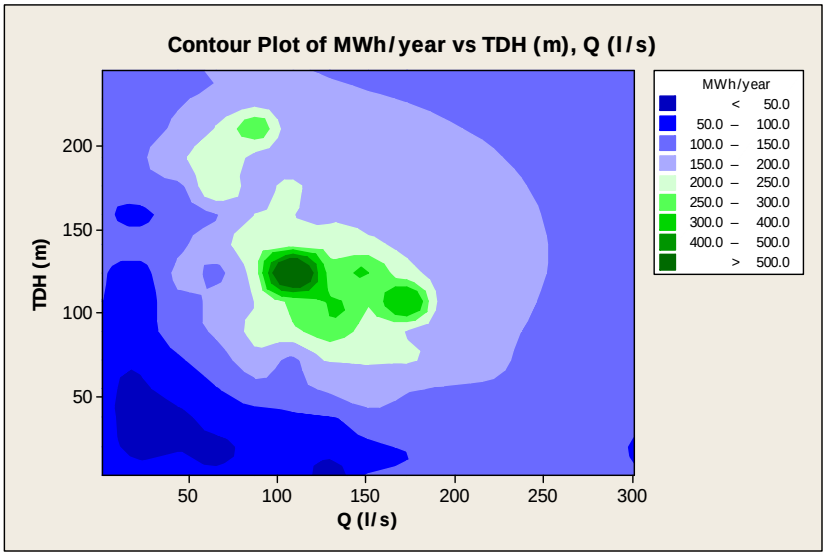


Figure 3B-4: Contour plot for well pumps, TDH (m) vs. Q (l/s) arranged by energy consumption (MWh/year)



Pumps consuming a lot of energy do not necessarily have a high OPPE, though small efficiency values are dominant in the case of low energy consumption (92% of pumps with OPPE < 50% consume less than 200 MWh/year).

Trends and correlations between variables (non-well pumps)

In non-well pumps, the trends are not so clear as in well pumps though again, higher values of TDH, Q and input kW correspond to better OPPE (Figure 3B-5). Only 19% of pumps with TDH over 60 m and 38% of pumps with Q > 300 l/s have OPPE < 50%. But 43% of pumps with TDH below 60 m and 40% of pumps with Q < 300 l/s have OPPE < 50%. That means that TDH values are more related with OPPE than Q. Also, only 15% of pumps with input power over 100 kW have OPPE < 50%.

In this case, high values of kWh/m^3 are not necessary related with lower OPPE (Figure 3B-5d). Anyway, only 10% of pumps consuming more than 1 kWh/m^3 have an OPPE over 50%.

For non-well pumps, the patterns when relating the variables with the annual consumption are not obvious (Figure 3B-6). Most pumps with TDH < 60 m (82%) consume less than 100 MWh/year but only 46% of pumps with TDH > 60 m use less than 100 MWh/year. It is interesting to note that high annual consumptions are related to lower flows (70% of pumps consuming more than 200 MWh/year have Q < 300 l/s). No relation is found between annual power consumption and energy use per volume pumped. 77% of pumps consuming more than 100 MWh/year have OPPE > 50% while 59% of pumps using less than 100 MWh/year have OPPE > 50%.

Figure 3B-5: Correlations for non-well pumps, OPPE (%) vs. other variables: a) TDH (m); b) Q (l/s); c) input power (kW); d) kWh/m^3

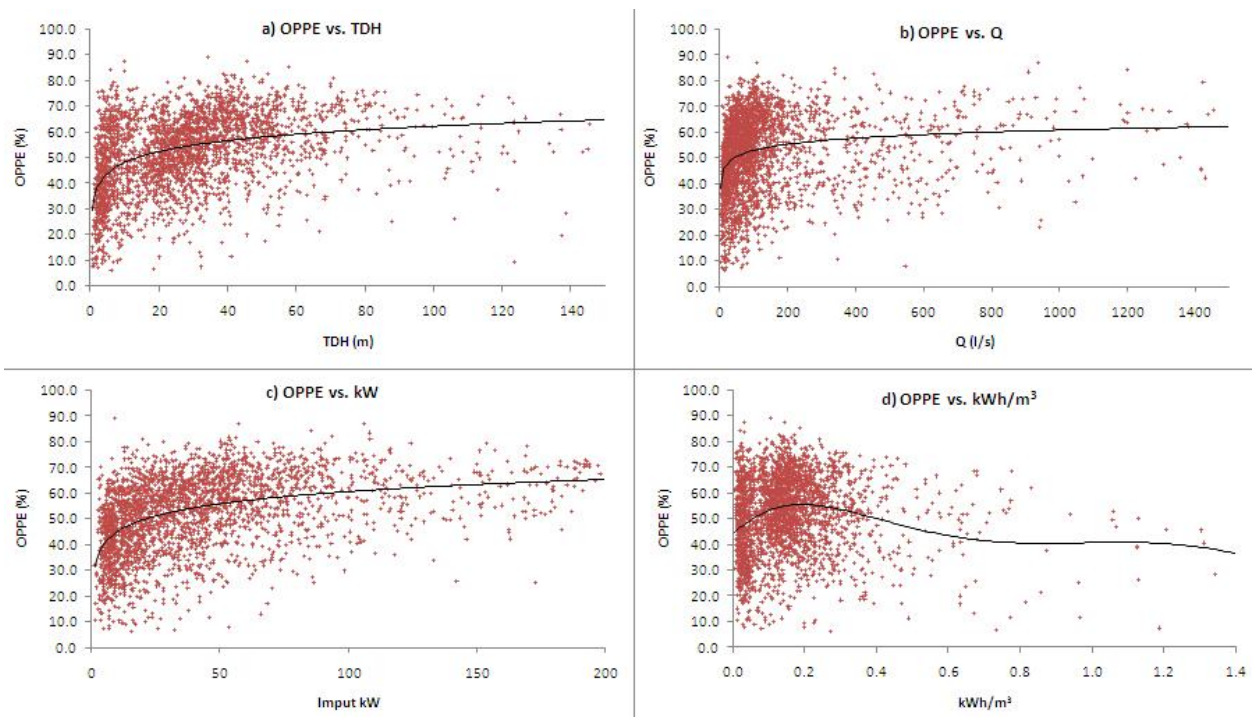


Figure 3B-6: Correlations for non-well pumps, energy consumption (MWh/year) vs. other variables: a) TDH (m); b) Q (l/s); c) input power per volume pumped (kWh/m^3); d) OPPE (%)

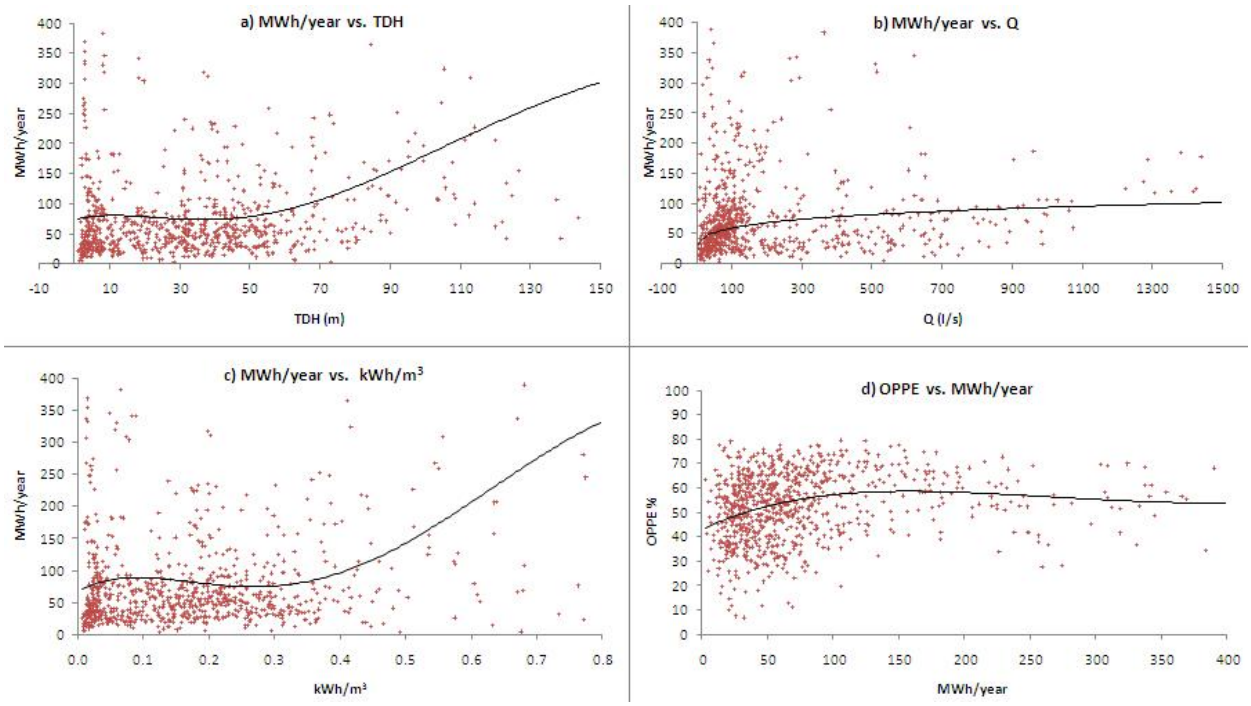
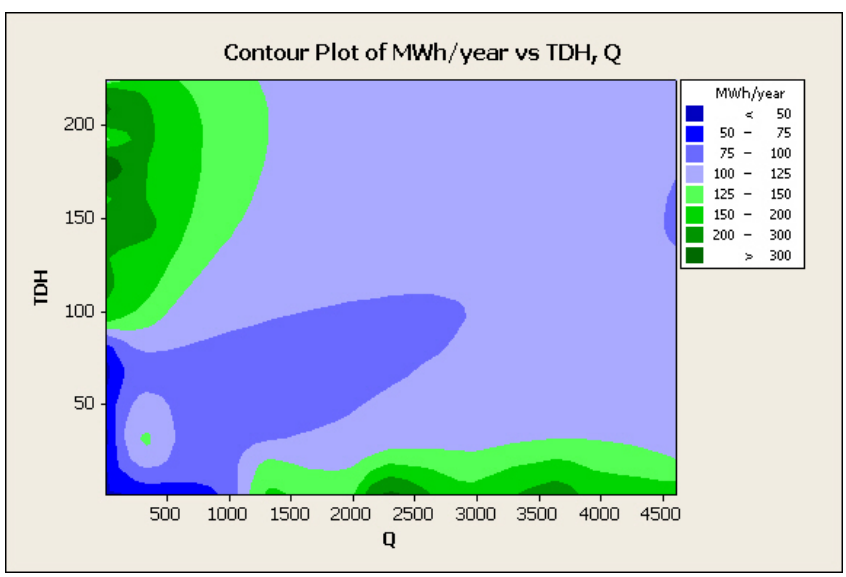


Figure 3B-7 shows the conjunctive effect of TDH and Q in annual power consumption. When both variables are small, the consumption also remains low. But for high TDH and low Q or vice versa higher consumptions are observed, as one would expect.

Figure 3B-7: Contour plot for non-well pumps, TDH (m) vs. Q (l/s) arranged by energy consumption (MWh/year)



Energy savings analysis

Pumps work in different conditions. Their operation and therefore their efficiency and energy consumption are in some way affected by these working circumstances. For this reason, categories were made according to annual energy consumption, TDH, and Q to determine the possible energy savings that might be achieved. This involves comparing the performance of a pump against the average performance in the same category.

The category ranges were selected according to the distribution of number of pumps with certain values for the variables considered.

Table 3B-1 shows, for each category of well pump, the average values of OPPE and MWh/year, the number of pumps in the group, the percentage of pumps which can be improved, the total potential energy savings and the average per pump and the money saved in each case.

The above-mentioned relationships between TDH and Q with OPPE are confirmed: average values of OPPE are better when TDH and Q are higher.

Table 3B-1: Potential energy savings for each category in well pumps

MWh/y	TDH (m)	Q (l/s)	Av. OPPE (%)	Av. MWh/y	MWh saved	Av. MWh saved	Number of pumps	% of pumps achieving savings	$ saved per year (average case)	$ saved per year (total)
>800	60-75	>100	52.7	921.8	554.7	138.7	5	80.0	$20,801	$83,204
	75-90	>100	59.4	1041.5	777.3	194.3	5	80.0	$29,147	$116,589
	90-120	<100	61.3	973.1	784.0	196.0	5	80.0	$29,400	$117,598
		>100	69.3	1170.8	1056.7	105.7	11	90.9	$15,850	$158,503
	> 120	<100	64.7	948.3	784.7	112.1	8	87.5	$16,816	$117,710
		>100	66.7	1357.5	329.7	109.9	4	75.0	$16,486	$49,459
400-800	<60	<100	47.4	520.4	415.7	103.9	5	80.0	$15,588	$62,351
		>100	60.7	472.8	258.7	51.7	6	83.3	$7,761	$38,804
	60-75	<100	51.7	527.9	1023.5	93.0	12	91.7	$13,957	$153,525
		>100	57.2	512.1	1065.8	106.6	12	83.3	$15,987	$159,871
	75-90	<100	63.1	460.9	730.6	48.7	17	88.2	$7,306	$109,594
		>100	63.1	444.7	628.5	57.1	12	91.7	$8,571	$94,280
	90-120	<100	60.7	502.7	1888.0	89.9	24	87.5	$13,485	$283,194
		>100	64.7	518.2	485.8	54.0	10	90.0	$8,097	$72,875
	> 120	<100	60.6	576.0	823.7	117.7	8	87.5	$17,652	$123,562
		>100	71.2	447.9	133.1	22.2	7	85.7	$3,327	$19,964
300-400	<60	<100	51.3	320.2	209.8	52.4	5	80.0	$7,866	$31,463
		>100	61.0	336.3	142.4	23.7	7	85.7	$3,559	$21,356
	60-75	<100	58.0	353.1	1320.2	69.5	21	90.5	$10,422	$198,026
		>100	64.3	345.1	631.9	42.1	17	88.2	$6,319	$94,788
	75-90	<100	58.0	335.6	782.0	52.1	16	93.8	$7,820	$117,301
		>100	65.1	344.8	963.4	45.9	23	91.3	$6,881	$144,509
	90-120	<100	55.4	344.8	1345.7	84.1	18	88.9	$12,616	$201,855
		>100	63.8	344.4	2295.2	47.8	55	87.3	$7,172	$344,278
	> 120	<100	64.8	335.9	446.6	63.8	8	87.5	$9,570	$66,988
		>100	69.5	363.9	282.1	23.5	13	92.3	$3,527	$42,320

Table 3B-1 continued: Potential energy savings for each category in well pumps

MWh/y	TDH (m)	Q (l/s)	Av. OPPE (%)	Av. MWh/y	MWh saved	Av. MWh saved	Number of pumps	% of pumps achieving savings	$ saved per year (average case)	$ saved per year (total)
200 - 300	<60	<100	51.3	234.7	766.0	76.6	12	83.3	$11,490	$114,897
		>100	57.2	239.5	1074.4	39.8	31	87.1	$5,969	$161,165
	60-75	<100	56.5	235.9	2233.8	42.1	58	91.4	$6,322	$335,065
		>100	61.8	245.8	1544.6	40.6	44	86.4	$6,097	$231,683
	75-90	<100	54.3	236.1	3071.7	55.8	62	88.7	$8,377	$460,761
		>100	64.6	247.9	2657.2	40.3	77	85.7	$6,039	$398,573
	90-120	<100	57.7	231.6	4106.8	39.1	117	89.7	$5,867	$616,021
		>100	67.1	255.8	1902.6	28.0	81	84.0	$4,197	$285,390
	>120	<100	58.4	243.1	1750.7	38.1	51	90.2	$5,709	$262,605
		>100	71.9	262.5	134.5	16.8	9	88.9	$2,522	$20,179
100 - 200	<60	<100	51.0	134.3	5558.9	33.1	190	88.4	$4,963	$833,839
		>100	58.7	135.8	3136.9	22.7	154	89.6	$3,410	$470,542
	60-75	<100	55.1	141.2	5652.8	29.9	208	90.9	$4,486	$847,924
		>100	64.6	149.8	1093.6	17.6	69	89.9	$2,646	$164,045
	75-90	<100	56.9	146.8	5142.2	31.5	186	87.6	$4,732	$771,337
		>100	68.4	156.0	362.7	16.5	26	84.6	$2,473	$54,404
	90-120	<100	59.4	144.5	6403.1	27.5	263	88.6	$4,122	$960,458
		>100	68.2	167.5	734.5	21.0	41	85.4	$3,148	$110,169
	>120	<100	61.8	141.7	2067.7	23.8	99	87.9	$3,565	$310,158
		>100	73.3	160.4	33.3	8.3	5	80.0	$1,248	$4,993
50 - 100	<45	<100	51.1	67.8	5545.6	16.3	378	89.9	$2,447	$831,846
		>100	56.5	73.0	2570.5	15.0	192	89.1	$2,255	$385,573
	45-75	<100	56.5	70.7	7850.7	14.2	615	89.9	$2,129	$1,177,608
		>100	65.6	83.3	378.7	11.1	39	87.2	$1,671	$56,806
	75-100	<100	59.1	74.9	3426.0	14.6	267	87.6	$2,196	$513,897
	>100	<100	60.5	77.9	1480.1	12.7	129	90.7	$1,898	$222,022
< 50	<45	<100	50.9	32.9	6221.5	7.9	875	89.5	$1,192	$933,222
		>100	58.0	37.0	485.9	6.8	79	89.9	$1,027	$72,892
	45-75	<100	54.5	34.4	3652.3	6.8	594	90.1	$1,024	$547,852
		>100	63.4	20.2	13.2	2.2	8	75.0	$329	$1,976
	75-100	<100	55.9	35.8	738.7	7.5	113	87.6	$1,119	$110,808
	>100	<100	55.2	31.3	163.6	6.8	29	82.8	$1,023	$24,547
	Averages					49.6	5435	86.9	$7,442	
	Total				102114.81					$15,317,221

Potential energy savings are obviously much higher for the pumps with more annual power consumption. In fact, by only targeting 131 pumps over 400 MWh/year (2.5% of total number of well pumps), 12% of total savings can be achieved, as the average saved per pump is high (100 MWh/year/pump).

It is also important to pay attention to the percentage of pumps with potential savings as this can give an idea of which categories have worse performance.

Table 3B-2: Potential energy savings for each category in non-well pumps

MWh/year	Q (l/s)	TDH (m)	Av. OPPE (%)	Av. MWh/y	MWh saved	Av. MWh saved	Number of pumps	% of pumps achieving savings	$ saved per year (average case)	$ saved per year (total)
> 300	<60	>30	52.8	488.8	1853.9	154.5	13	92.3	$23,174	$278,091
	60-130	>30	59.7	637.4	448.7	89.7	7	71.4	$13,460	$67,302
	130-250	>30	53.9	398.6	179.2	35.8	5	80.0	$5,375	$26,876
	250-500	<30	54.2	357.7	538.2	89.7	6	83.3	$13,454	$80,724
		>30	69.3	551.1	156.2	31.2	6	83.3	$4,686	$23,433
	>500	<30	50.2	438.2	992.3	99.2	11	90.9	$14,885	$148,849
100-300	<60	>30	55.8	166.1	1284.8	45.9	35	80.0	$6,883	$192,727
	60-130	>30	63.2	156.6	1193.4	27.8	50	86.0	$4,163	$179,012
	130-250	<30	56.9	189.2	81.2	27.1	4	75.0	$4,060	$12,180
		>30	64.4	171.4	436.0	20.8	23	91.3	$3,114	$65,397
	250-500	<30	53.0	141.2	484.0	44.0	13	84.6	$6,600	$72,604
	>500	<30	51.6	162.7	1576.9	46.4	39	87.2	$6,957	$236,529
50-100	<60	<30	40.4	66.8	163.6	32.7	6	83.3	$4,909	$24,545
		>30	52.7	65.2	842.3	15.9	61	86.9	$2,384	$126,345
	60-130	<30	45.1	65.3	682.7	19.5	40	87.5	$2,926	$102,410
		>30	59.0	70.4	1228.8	14.0	101	87.1	$2,095	$184,327
	130-250	<30	54.2	70.1	392.4	17.8	25	88.0	$2,675	$58,859
		>30	68.6	83.8	68.2	9.7	8	87.5	$1,460	$10,223
	250-500	<30	50.4	71.6	519.9	20.0	29	89.7	$3,000	$77,987
	>500	<30	55.5	75.7	681.3	20.0	40	85.0	$3,006	$102,195
< 50	<60	<30	40.5	23.9	231.6	7.7	35	85.7	$1,158	$34,742
		>30	50.6	31.4	1101.5	8.7	141	89.4	$1,311	$165,220
	60-130	<30	47.7	31.2	524.2	9.7	59	91.5	$1,456	$78,633
		>30	61.3	39.9	87.5	6.3	16	87.5	$938	$13,125
	130-250	<30	44.8	27.7	302.6	8.0	44	86.4	$1,194	$45,383
	250-500	<30	53.0	30.6	281.6	6.4	48	91.7	$960	$42,246
	>500	<30	53.5	32.0	253.5	8.7	32	90.6	$1,311	$38,024
	Averages					34.0	897.00	86.0	$5,096	
	Total				16586.6					$2,487,988

The grouping of data provides some other interesting insights. For instance, within the same annual consumption category, pumps with flow higher than 100 l/s on average have more energy consumption than those with less flow, even if the TDH is much higher. As an example, the average energy consumption for pumps in the range of 200-300 MWh/year with TDH < 60 m and Q > 100 l/s is 240 MWh/year while pumps with Q < 100 l/s and TDH between 75-90 and 90-120 m consume 236 and 231 MWh/year.

Table 3B-2 shows the same information for non-well pumps. In this case, more divisions have been made according to Q values as the range is wider than in the case of well pumps. Again, targeting pumps over 300 MWh/year would result in higher savings: action taken on only 41 pumps (4% of the total) would achieve 25% of total potential savings. Higher savings seem to be expected in the groups of pumps with low Q and high TDH.

According to this analysis, energy savings of more than 102,100 MWh/year could be achieved for well pumps, with an average per pump of 49 MWh/year. In the case of non-well pumps, the total potential savings are over 16500 MWh/year and the average savings for each pump are 34 MWh/year. Hence, more energy can be saved per pump targeting well pumps.

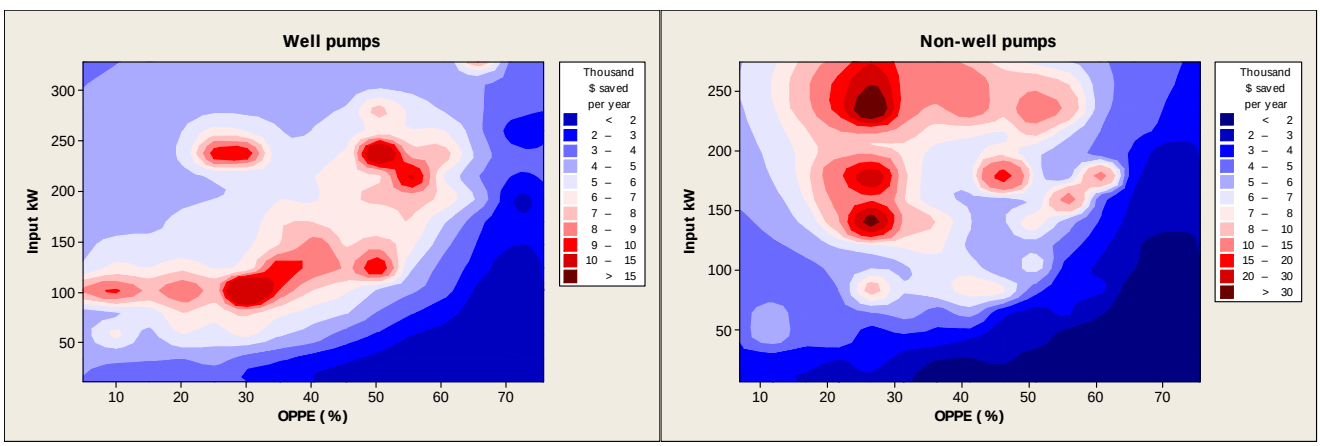
Therefore, if the pump performance is improved to meet the average OPPE of each group, around $7,400/year in savings are obtained per well pump and $5,000/year per non-well pump. These savings will depend on the result of the improvement and the price of energy. Whether the investment will be worthy or not depends on the cost of the improvement. Sometimes small repairs help to improve the performance of the pump with a reduced cost which will be profitable. When the repair cost is higher or if the pump replacement is necessary, the profitability depends on the initial condition of the pump, the savings achieved with the improvement of upgrading and obviously on the cost. In general, booster pump repairs are less expensive than well pump repairs, given the same kW size.

Figure 3B-8 shows a contour plot which relates Input kW and OPPE with potential savings obtained (in Thousand $ per year) for the well and non-well pumps which can be improved (OPPE below the average of the group). Obviously, pumps with higher OPPE would have lower savings as a lower increment in efficiency improvement would be obtained. Additionally, there will be lower savings if the input power is low in both well and non-well pumps. This fact is clearer in the case of non-well pumps.

For well pumps, high savings are observed in a range of input power near 100 kW and also close to 250 kW. When OPPE is around 50% there is a range between 200 and 250 kW with high potential savings.

In the case of non-well pumps, the higher savings are related to initial OPPEs between 20 and 30% for values over 130 kW of input power. Pumps with 50-55% of OPPE and input powers over 200 kW also show high savings.

Figure 3B-8: Contour plot of Input kW vs. OPPE (%) arranged by money savings (Thousand $/year)



CONCLUSIONS

1. The proportion of non-well pumps susceptible to improvements is slightly higher than for well pumps but more potential energy savings are obtained per well pump.
2. Well pumps with lower TDH and Q usually have poorer OPPE values. High flow rates and input power are typically associated with better OPPE values.
3. Low values of OPPE are observed for non-well pumps with high Q and low TDH or pumps with low Q and high TDH. These pumps also tend to have higher annual energy consumption.
4. Big well pumps providing high flows and TDH do not necessarily have a higher annual energy consumption than other pump categories.
5. There was a wide range of OPPE for pumps with large annual energy consumption (MWh/year). This is interesting because one might assume that extra attention would be paid to OPPE, if there are large annual power bills.
6. Pumps with low annual energy consumption have lower-than-typical efficiencies.
7. In order to maximize energy savings by targeting the least number of pumps, those with high annual energy consumption should be the objective of improvements - especially well pumps with low TDH and input power or non-well pumps with low flow rate.
8. It is most economical to target pumps with high energy consumption and low input power (but operating many hours per year) as the motor size and pump size is usually relatively small and is therefore relatively inexpensive to modify.

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APPENDIX 3C:
Low Pressure Drip/Micro System Design: Analysis of Potential Rebate

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Drip/micro-irrigation systems are often referred to as "low pressure" systems because the required emitter pressures are relatively low (6-12 psi). However, the pump discharge pressures of systems on flat ground throughout California average 40 psi. This white paper examines readily attainable system losses by examining individual components of the drip/micro system.

***Bottom Line* – Pump discharge pressures can be reduced by 13 to 17 psi if the appropriate system hardware is selected and pipelines are sized to minimize friction losses.**

In the southern San Joaquin Valley, the per-acre energy savings and demand reduction as a result of this reduction in pump discharge pressure is shown in the summary table below. Based on the kWh/Acre/Yr savings, a cost savings of $25-$30 per acre could be expected per year.

Summary Table: Estimated annual kilowatt-hour (kWh) per acre and kilowatt (kW) demand per acre in the southern SJV for a typical year

Crop Category	Energy Savings (kWh/Acre/Yr)	Demand Reduction (kW/Acre)
Deciduous Orchards	**192**	**0.10**
Vines	**125**	**0.08**
Row Crops (Tape)	**132**	**0.13**

As is often the case, system improvements bring with them an increased cost for appropriate hardware (valves, filters, emitters, larger pipelines, etc.). A rebate program would be beneficial to encourage energy efficiency by lowering system pressure demands. A good rebate program would not only specify discharge pressures based on readily attainable system pressure losses and elevation changes throughout the field, but would also specify a reasonable new system distribution uniformity of 0.92. A high new system distribution uniformity ensures that the new system will apply water uniformly over the field, potentially minimizing irrigation water losses below the root zone and providing excellent distribution of fertilizers through the irrigation system.

Low Pressure Drip/Micro System Design

Background and Baseline Data

The terms "drip irrigation", "microirrigation", and "trickle irrigation" are often used interchangeably, although they can technically refer to the design of the final emission device. These systems are often referred to as "low pressure systems". A typical California pump discharge pressure is about 35-45 psi (pounds per square-inch, pressure measurement) on flat ground (even though the emitter may need only 6-12 psi pressure). For a detailed explanation of options and designs for drip/micro systems, refer to Burt and Styles (2011).

ITRC maintains a database of over 700 drip/micro system distribution uniformity evaluations that have been conducted throughout California every summer since 1997. Approximately 350 of these evaluations were selected throughout California's Central Valley where the systems are constructed on relatively flat terrain. From these evaluations, the average pump discharge pressure and standard deviation of the discharge pressures is shown in the following table.

Table 3C-1: Average and standard deviation of pump discharge pressures for 350 drip/micro systems on flat terrain in the California Central Valley

Sample Size	Average Pump Discharge Pressure	Standard Deviation
350	40 PSI	13 PSI

A study by Trout and Gartung (2002) highlighted several important topics related to energy and drip/micro-irrigation. An important aspect of their findings is the discrepancy between the fact that while typical emitters only need 6-12 psi of pressure, drip/micro system pump discharge pressures average about 40 psi on flat ground. With advances in valve and filtration design in recent years, proper design of drip/micro systems should be able to reduce the overall discharge pressure significantly.

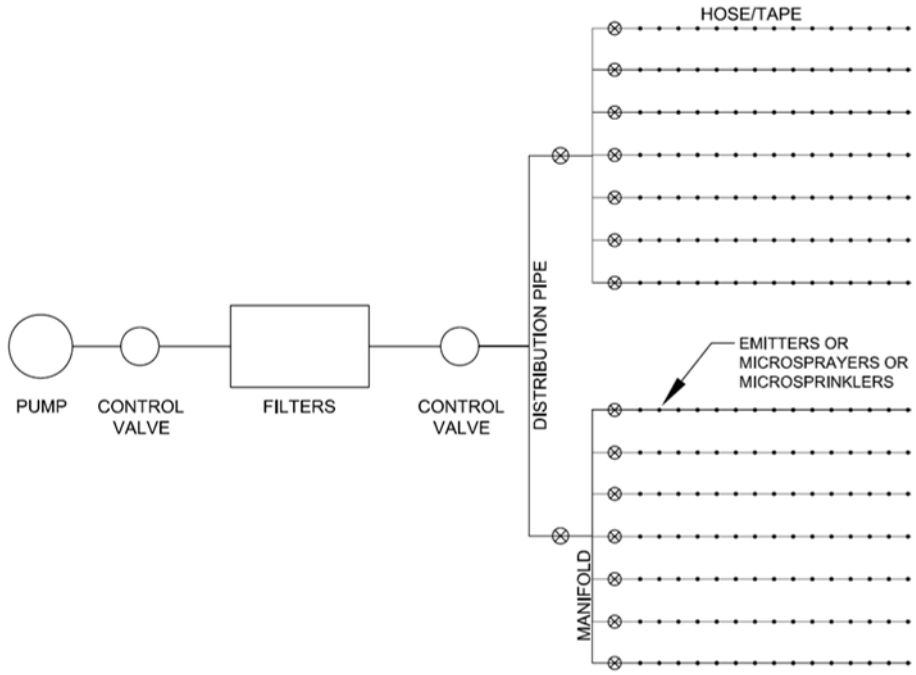
Designing a system for a lower pump discharge pressure will reduce both electrical load (demand) and annual energy consumption of the motor driving the pump over the life of the system.

This document will outline reasonable drip/micro system component losses and develop criteria for appropriate system designs based on the traditional distribution uniformity plus a maximum pump discharge pressure target.

Readily Attainable Pressure Losses

Figure 3C-1 is a conceptual sketch of a drip/micro-irrigation system with key components.

Figure 3C-1: Drip/micro-irrigation system schematic



To minimize pressure requirements at the pump discharge, one must consider the pressure requirements for water to flow through each of these components.

1. Control valves near the filter. All control valves have friction loss, but there are significant differences between various sizes and models. There is very little new knowledge here, and some excellent control valves exist for this location.

2. Filters. This is one component that has significant room for improvement. Therefore, ITRC conducted a major study of media filter performance as part of this contract. The large pressure loss that is built into drip and micro-irrigation systems for filters is not needed if the correct filters are used. The major factors are:
    a. Some filters, such as the various internal-wand-cleaning screen filters, and various disc filters, require 35 psi minimum to properly backflush.
    b. Media filters (the most common type) are generally thought to require 35 psi to backflush. The ITRC filter study shows this is not a universal requirement.

    Because the filter backflush pressure requirement is so large, there is typically no reason for designers to select low pressure loss valves and fittings within the irrigation system. In other words, the items discussed below are not very important unless the proper filter is selected.

3. Control/pressure regulation valves within the distribution system, and at the heads of tapes and hoses. Depending upon the model and design, there can be significant pressure savings if valves are carefully selected. There are two types of pressure regulation valves:
    a. Pilot-operated valves. These are usually 2" or larger in diameter, and are used at the heads of manifolds, especially with tape systems. There is a major, little-known hydraulic fact about many of these valves: if the downstream pressure is 8 psi (typical for drip tape), there may be a 10 psi loss across the valve for a flow of 100 GPM. But if the downstream pressure is 20 psi, there may only be a 2 psi loss across the valve for a flow of 100 GPM. Manufacturers publish the 2 psi value, but not the 8 psi valve. Irrigation designers do not know which valves have these characteristics, or that they even have them. Designers do know that they need a substantial "safety factor" of extra psi for the pump to take care of things like this.
    b. Pre-set pressure regulators. These pressure regulators are typically used at the heads of hoses in hilly terrain. They can have large (3-6 psi) friction losses across them when wide open.

4. Fittings on hose risers can be small and have appreciable friction loss. There is no standard in the industry for these fittings, and the friction loss of the various assemblies that are used is not well known.

5. Drip hose/tape hydraulics. These are fairly well understood. All of the major manufacturers have good hydraulics programs that they provide to irrigation designers. ITRC has a similar program for education that is used by many designers. They all perform the same functions – the uniformity of water discharge, friction, pressure requirements, etc. are automatically computed if one inputs the slope, hose diameter, emitter specifications, and other required information.

6. Emitters, microsprayers, and microsprinklers. These are the final emission devices. Many of the designs have not changed for many years. For discussion, there are two basic types of emission devices: Those with fixed holes, and those with some type of pressure compensating (PC) ability that requires some type of flexible diaphragm inside the emission device. There are some very interesting possibilities at this level, which are described below:
    a. Standard, fixed hole/path emitters must have a minimum pressure of 6-12 psi just to maintain good uniformity of discharge along the hoses, and between hoses. If there is elevation variation, the optimum average pressure needs to be higher to maintain good uniformity.
    b. Pressure compensating (PC) devices present interesting possibilities:
        i. There are very few PC emitters (discharging somewhere between 0.5 and 1.0 Gallons/hour) that can operate very well at pressures as low as 4 or 5 psi. This means that at a wide range of pressures, say between 4 and 35 psi, the flow rate is almost identical. Especially for hilly terrain, this feature can offer substantial (at least 10 psi) pressure reduction benefits.
        ii. Microsprinklers are emission devices that have a stream of water (e.g., 15 Gallons/hr) that is rotated to provide a large amount of ground coverage. The most popular PC microsprinklers do not work well until the pressure at the microsprinkler is about 25 psi. ITRC was unable to locate any commercially available low pressure PC microsprinklers.

iii. Microsprayers are emission devices with relatively large flows (e.g., 15 Gallons/hr) that discharge from a nozzle, hit a fixed plate, and then spray out with multiple jet patterns. Bowsmith Industries (Exeter, CA) recently developed a PC microsprayer that begins to function well at relatively low pressures (8 psi). As with PC emitters, this is an important addition for hilly terrain.

Considering the individual component pressure requirements, the readily attainable pressure losses are shown in the following table.

Table 3C-2: Readily attainable pressure losses

Item	Pressure (psi) required for different systems	
	Tape	Tree/vine
Emitter	6	10
Hose/tape	3	3
Fittings, valve losses	2.5	2.5
PVC main and manifold	3.5	3.5
Filter	5	5
Control valves, check	3	3
TOTAL	**23**	**27**

Energy Savings

Reducing the pump discharge pressure from an average of 40 psi to 23 psi for tape and 27 psi for trees and vines will result in lower energy consumption assuming that the same amount of water is applied to the crops in both cases and the overall pumping plant efficiencies are the same.

Table 3C-3 shows the estimated annual applied irrigation water per acre for three crop categories under drip/micro-irrigation in the southern San Joaquin Valley (SJV). These values were obtained from the ITRC website (ITRC, 2003) for the California Department of Water Resources ETo Zone 16.

Table 3C-3: Estimated annual applied irrigation water for three crop categories in the southern SJV

Crop Category	Applied Irrigation Water (AF/Acre/Year)
Deciduous Orchards	3.7
Vines	2.4
Row Crops (Tape)	2.0

The energy savings per acre-foot of applied water can be computed as:

$$\frac{kWh}{AF} = \left(\frac{\Delta TDH}{OPPE/_{100}}\right) * 1.023$$

Where,

kWh/AF = savings in kilowatt-hours per acre-foot of water per year

ΔTDH = difference discharge pressure between the baseline (40 psi) and the readily attainable pressure loss shown as total dynamic head (feet) where (TDH = 2.31×psi)

OPPE = overall pumping plant efficiency as a percent

The energy savings per acre is computed as:

$$\frac{kWh}{acre} = \left(\frac{kWh}{AF}\right) * AF$$

Where,

kWh/Acre= savings in kilowatt-hours per acre per year

AF = acre-feet of applied irrigation water per year

Assuming an overall pumping plant efficiency of 60% (considered good to very good for typical motor sizes used in agricultural pumping), the estimated energy savings per acre per year resulting in a reduction in discharge pressure from 40 psi on average to 23 psi or 27 psi (for row crops with tape or deciduous orchards and vines, respectively) is shown in **Table 3C-4**.

Table 3C-4: Estimated per acre annual energy savings through reduced pump discharge pressures

Crop Category	Pump Discharge Pressure Difference		Savings	
	Δpsi	ΔTDH	kWh/AF	kWh/Acre/year
Deciduous Orchards	13	30.0	51.2	**192**
Vines	13	30.0	51.2	**125**
Row Crops (Tape)	17	39.3	67.0	**132**

Demand Reduction

By reducing the required pump discharge pressure, the electrical demand or load of the motor is also reduced. Irrigation systems are, for the most part, designed to meet the peak evapotranspiration demands of the crop that is being irrigated. In some cases the systems may be designed considering special constraints such as weekday operation only or to operate during the non-peak electrical period. However, in many cases the systems are designed so that the pump runs continuously during the peak evapotranspiration period. In California, the peak evapotranspiration period of most crops coincides with the peak electricity demand period (i.e., June-August).

Peak monthly crop evapotranspiration data for a typical year was obtained for the crop categories shown in **Table 3C-5** (ITRC, 2003) for the southern SJV. The estimated peak irrigation demands in gallons per minute per acre (GPM/Acre) was computed and is shown in the table.

Table 3C-5: Estimated peak irrigation demands (gross requirement) for three crop categories in the southern SJV (ETo Zone 16)

Crop Category	Peak Irrigation Demands (GPM/Acre)
Deciduous Orchards	10.3
Vines	8.2
Row Crops (Tape)	10.4

The reduction in demand can be computed based on the flow rate demands shown in **Table 3C-5**, an assumed overall pumping plant efficiency of 60%, and the reduction in total dynamic head for the low pressure drip/micro system design.

$$kW = \frac{(GPM * \Delta TDH)}{(3960 * \frac{OPPE}{100})} * 0.746$$

Where,

kW = reduction in kilowatt demand per acre

ΔTDH = difference discharge pressure between the baseline (40 psi) and the readily attainable pressure loss shown as total dynamic head (feet) where (TDH = 2.31×psi)

OPPE = overall pumping plant efficiency as a percent

The estimated reduction in demand on a per-acre basis is shown in **Table 3C-6**.

Table 3C-6: Electric demand reduction through reduced pump discharge pressure requirements in the southern SJV

Crop Category	Pump Discharge Pressure Difference		Reduction
	Δpsi	ΔTDH	kW/Acre
Deciduous Orchards	13	30.0	**0.10**
Vines	13	30.0	**0.08**
Row Crops (Tape)	17	39.3	**0.13**

Rebate Programs for Drip/Micro-Irrigation

Drip/micro-irrigation rebate programs offer substantial holistic potential benefits in terms of improved fertilizer efficiency and increased yield. These two items can produce more crop per drop of fertilizer and water consumed.

Such rebate programs might require numerous specific features such as the correct flow rate, appropriate air vents, good fertilizer injectors, certain thicknesses of tape, and so on. But perhaps more importantly, the following key performance results should be specified:

3. The new system Distribution Uniformity, as measured with the Cal Poly ITRC drip/micro-irrigation evaluation procedures, must be greater than 0.92.
4. The pump discharge pressure shall be no greater than the following:
   a. For tape systems: 23 psi, plus the difference in elevation between the highest point in the field and the pump discharge.
   b. For emitter and micro-spray systems: 27 psi, plus the difference in elevation between the highest point in the field and pump discharge.

Perhaps there could be a $200/acre rebate for new systems meeting the pressure and uniformity criteria, plus an additional $40/acre rebate for every psi reduction below the "total" listed above.

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APPENDIX 3D:
Variable Frequency Drive (VFD) Controlled Irrigation Pumps: Analysis of Potential Rebate

Well pumps, booster pumps, and a combination of the two are used throughout the agricultural sector to provide water for on-farm irrigation. However, the pump discharge pressures for the majority of irrigation systems are excessive (Burt, 2009), waiving considerable monetary and power consumption savings. This attachment analyzes the numerous potential benefits of integrating a variable frequency drive (VFD) to irrigation supply systems and modifying system design philosophies.

> ***Bottom line*** – Pump discharge pressures can be reduced with appropriate design procedures and the integration of a VFD on well pumps.

In 2002, ITRC (Burt and Howes, 2002) surveyed five California irrigation districts regarding the integration of VFD controllers to supply pumps. The results were positive across the board including substantial reductions in energy costs, reduced peak load demand, and other savings related to less vehicular travel and manpower. Annual paybacks were in the 2-4 year range.

For on-farm irrigation, VFDs will not provide as many secondary benefits to the owner as for irrigation districts, because their operations are not similar. Nevertheless, substantial benefits can be achieved on-farm.

Table 3D-1 summarizes the results that are discussed in this Appendix. Key assumptions for **Table 3D-1** are:

Location = West side of the San Joaquin Valley, Kern County

Price of power = $0.16/kWh

Table 3D-1: Estimated annual kWh savings in western Kern County if VFDs are installed on pressurized field irrigation systems of 160 acres.

Crop Type	Annual kWh savings with VFD	
	Category 1 – Booster pump only.	Category 2 – Well pump plus booster or well pump only supplies pressure to drip/sprinkler irrigation system.
Deciduous Trees	21,078	64,176
Grape Vines	13,672	41,667
Tape on Produce Crops	13,672	41,667

Variable Frequency Drive (VFD) Controlled Pumps

Pressure Reduction with VFDs

VFD controllers for irrigation pump motors may have the greatest potential for immediate power savings. There are numerous reasons to promote VFDs on both well pumps and booster pumps. The two most significant reasons are:

1. Designers must always over-design pumps. Farmers do not complain if they have too much pressure; but they definitely complain if they do not have enough. The uncertainties with pump design are:
   a. Designers always include a "safety factor" of at least 5 psi in a design – whether needed or not.
   b. Published pump curves often do not exactly match what goes into a field.
   c. The pressures from irrigation district pipeline turnouts vary over time, and may not even be known by the designer.
   d. Well water levels vary from year-to-year, and from Spring to Fall. These variations can easily be 50 feet.

2. Irrigation systems do not require a constant pressure. In general, irrigation systems incorporate sequences of multiple blocks. These blocks have varying elevations and sizes, each with unique pressure requirements.

Given the two items above, VFDs allow designers to over-design the pump to meet uncertainties and occasional extreme conditions, without having continuous power wastage due to an over-designed pump.

The power savings that are obtained from a VFD will depend upon the specific installation. In the case of well pumps for which the lift from the pumping water level to the ground surface is substantial, the power savings are not properly predicted using the affinity law equation:

$$(\text{New kW}/\text{Old kW}) = (\text{New RPM}/\text{Old RPM})^3$$

The equation above assumes that the flow rate varies proportionally as the RPM changes. In irrigation, the RPM of the pump is changed in the case of fluctuating water levels, to maintain a constant GPM. In the case of irrigation block sizes that have variable elevations and GPM requirements, the relationship is more complex.

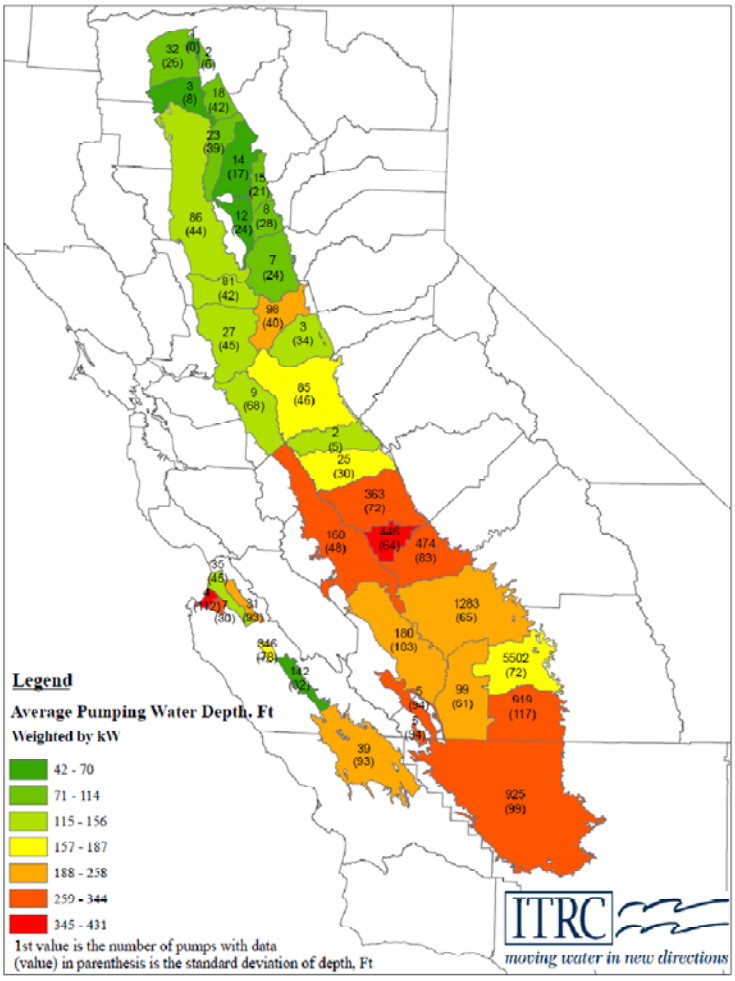
Readily attainable pressure savings estimates for a well pump are shown in the following table. These values are based on design experience of ITRC staff, and are therefore somewhat subjective.

Table 3D-2: Readily attainable pressure savings.

Pressure savings category	Estimate of pressure savings (ft)
Over-design for fluctuating water table	10% of the average pumping water level in the area
Over-design for unknown factors in system design	10
Variations in block sizes and locations	6
Total pressure savings, unadjusted	Depends on the average pumping water level in the area

As described in **Table 3D-2**, the magnitude of pressure savings will be proportional to the average pumping water level in the area. **Figure 3D-1** displays average pumping water levels of the pumps sampled, weighted by kW, for California's various groundwater basins. This white paper utilizes data from a reference region in western Kern County.

Figure 3D-1: Weighted pumping water depths from surveyed pumps (ft)



Three additional benefits derived from the use of VFDs are also substantial, although they do not in themselves reduce electricity consumption (kWh). These benefits are:

1. Water hammer and subsequent damage to the pump and irrigation system are reduced because of the slow start and slow stop capabilities of VFD-equipped pumps.
2. Farmers are much more likely to adopt time-of-use pumping practices with well pumps. This is because the slow starting of well pumps, as opposed to 100% speed starting (with subsequent very high flow rates), can have a drastic impact on the life of wells. Many farmers will not start or stop well pumps during the irrigation season because they are afraid the starts and stops will damage their wells.
3. The slow start minimizes large but temporary current loads on the electric utility grid.

Baseline Data

Table 3D-3 describes data obtained from the ITRC website (ITRC, 2003) for the reference area, specifically in California Department of Water Resources ETo Zone 16. In this case, ET of irrigation water is assumed to equal the applied water – making the assumption that farmers irrigate to the average condition of their fields and have both over- and under-irrigation on orchards and vines, but have slight over-irrigation on taped fields.

Table 3D-3: Estimated annual applied irrigation water for three crop categories in the southern SJV.

Crop Category	Applied Irrigation Water (AF/Acre/Year)
Deciduous Orchards	3.7
Vines	2.4
Row Crops (Tape)	2.4

Table 3D-4 reflects the average pumping data of the pumps sampled during the research completed for **Figure 3D-1** in the Kern County groundwater basin.

Table 3D-4: Typical well pump data in the Kern County groundwater basin, from Appendix 3C.

Kwh/AF	Input Kw	TDH (ft)	Pumping Water Level (ft)
555	127	321	300

Energy Savings

The next section will highlight the substantial energy and monetary savings possible tough the points previously discussed using collected data from the southern San Joaquin Valley (SJV) specifically in ETo Zone 16 for reference (western Kern County). To differentiate pressure

savings from the complex variety of irrigation supply systems, the calculations are divided into two categories.

Base Unit:

A well pump that supplies a booster pump for pressurized irrigation systems.

For this analysis, the "typical well pump data" in ***Table 3D-4*** *are used to compute the following:*

- *GPM of this pump = 1365 (assuming a 65% pumping plant efficiency)*
- *Hours necessary to pump 1 AF = 4 hours*
- *This size of a pump would typically irrigate about 160 acres of drip*

The new total dynamic head (TDH) (a.k.a., pressure) for the well pump is computed as:

Eq. 1: New $TDH = Old\ TDH - (PWL \times 0.1)$ - 16′

Where,

Old TDH	= Old TDH from **Table 3D-4** (321 ft)
PWL	= pumping water level (ft); in other words, the static water level (SWL) plus drawdown, from **Table 3D-4** (300 ft)
0.1	= Assumes 10% overdesign of TDH due to possible water table fluctuations
16′	= Factors from **Table 3D-2**, related to unknown variables that must be included in a pump design

$New\ TDH = 321' - 300' \times 0.1 - 16'$ = 275′

Assuming a constant flow rate requirement, power savings can be computed as:

Eq. 2: New $kW = \left(\frac{New\ TDH}{Old\ TDH}\right) \times Old\ kW$

Where,

Old kW = energy used to pump water, in kilowatts, from **Table 3D-4**

$New\ kW = \left(\frac{275'}{321'}\right) \times 127\ kW$ = 108.8 kW

Power Savings = Old kW – New kW

= 127 kW – 108.8 kW = 18.2 kW

The annual monetary saving per Category 1 pump is then computed as:

Eq. 3: $\frac{\text{Dollars}}{year} = \Delta\ kW \times \frac{Hrs}{yr} \times \frac{dollars}{kWh}$

Where,

$\Delta\ kW$ = kW savings calculated previously; (Old kW – New kW)

$\frac{Hrs}{yr}$ = typical hours of operation per year, which depends upon the crop and the area of the field served.

Table 3D-5: Hours of operation for the example well pump on 160 acres.

Crop	Annual applied, AF/Acre	Hours/year
Deciduous trees	3.7	2368
Vineyard	2.4	1536
Tape on row crop produce	2.4	1536

$\frac{dollars}{kWh}$ = typical cost per kWh. Assume $0.16/kWh.

For the deciduous trees,

$$\Delta \frac{kWh}{yr} = 18.2\ kW \times 2368 \frac{hours}{yr} = 43{,}098 \frac{kWh}{yr} for\ 160\ acres$$

$$\frac{\text{Dollars}}{year} = 43{,}098\ \frac{KWh}{yr} \times \frac{\$0.16}{kWh}$$

= $ 6896/yr for the well pump, only on 160 acres.

Table 3D-6: Well pump only VFD savings on a per crop basis – 160 acres.

VFD on Well Pump Only – Western Kern Co.		
Crop Category	**Hours/yr**	**Δ kWh/Year**
Deciduous Orchards	2368	43.098
Vines	1536	27,995
Tape on Produce Crops	1536	27,995

Booster Pump Only

A system that receives water from a canal or irrigation district, without any pressure.

The computations assume the following savings with a VFD on a booster pump:

Table 3D-7: Savings with a VFD on a booster pump.

Pressure Savings category	Estimate of pressure savings, ft.
Over-design for "safety factor"	11.5
Likely overdesign of pump or lack of trimming impellers	5
Adjustment due to kW impact caused by flow adjustment	6
Total pressure savings	**22.5 ft**

Assuming the same system as the previous well pump example, with a flow rate of 1365 GPM on 160 acres, with 65% pumping plant efficiency:

For deciduous orchards:

$$kW\ savings = 22.5\ ft\ \times \frac{1365\ GPM}{3960 \times .65} \times\ .746 \frac{kW}{HP}\ = 8.9\ kW$$

Using the same hours per year as with the well pump:

kWh savings/yr on deciduous trees = 8.9 kW × 2368 hours/yr = 21,078 kWh/yr saving

Table 3D-8: Booster pump VFD savings on a per crop basis – 160 acres.

VFD on Booster Pump Only – Western Kern Co.		
Crop Category	**Hours/yr**	**Δ kWh/Year**
Deciduous Orchards	2368	21,078
Vines	1536	13,672
Tape on Produce Crops	1536	13,672

Summary of kWh Savings

There are two general categories of pumps for pressurized on-farm systems (drip and sprinkler):

- ***Category 1*** – Booster only. Water is supplied from an irrigation district turnout, and a booster pump is needed to provide the pressure for the drip system. Even if the irrigation district supplies pressurized water, that pressure can vary over time so the designer must design the pump for the worst situation (lowest pressure from the turnout).
- ***Category 2*** – A well pump provides water directly to the drip system under pressure, or is directly linked to the drip system booster pump. For this case, the savings of the well pump only, plus the booster pump, are added.

The estimated annual power savings will depend upon the crop type and acreage. Well pump savings will depend upon the depth to standing water level as well. The table below has been developed for the western side of Kern County.

Table 3D-9: Estimated annual kWh savings in western Kern County if VFDs are installed on pressurized field irrigation systems of 160 acres.

Crop Type	Annual kWh savings with VFD	
	Category 1 – Booster pump only.	Category 2 – Well pump plus booster or well pump only supplies pressure to drip/sprinkler irrigation system.
Deciduous Trees	21,078	64,176
Grape Vines	13,672	41,667
Tape on Produce Crops	13,672	41,667

Rebate Programs for VFD and Pump Selection

Given that VFD controllers can provide substantial energy-related benefits with agricultural irrigation pumps, any rebate program for VFDs should contain minimum requirements for the purchase of VFD controllers, covering the following features:

1. Efficiency. Inefficient VFDs create excess heat, which requires significant air conditioning power to dissipate.
2. Temperature rating.
3. Power quality.
4. Form of the simulated sine wave.
5. Audible noise.
6. Length of power cords that can be used. Some low quality VFD units can only have a cable of about 20 feet long between them and the motor.
7. Means of cooling the VFD.
8. Allowable voltage variation between legs.
9. Allowable average voltage variation.

A rebate program should have a different scale for well pumps versus booster pumps. This is because there are additional benefits to using VFDs on well pumps, which include:

- The slow startup will enable farmers to take advantage of off-peak power programs that they might not otherwise utilize.
- The slow startup introduces less dirt into the irrigation system, which requires less filtration and less water used for backflushing of filters.

However, a rebate program designed primarily for kWh reduction, rather than load shedding, would not include well pumps that discharge into canals or pipelines that supply surface irrigation (furrow or border strip) fields. This is because the farmers easily adapt to the changing groundwater levels by managing their irrigation systems for less or more flow (as the groundwater levels fluctuate over time). In other words, the irrigation system adapts to the well flow rate.

In contrast, the flows from wells that supply drip or sprinkler systems must adapt to the constant or changing demands of the irrigation system. Therefore, VFD control of well pumps is desirable, and will save power, on such systems. These are the systems that must have over-designed pumps to provide enough pressure and flow in the worst condition – meaning excess pressure is supplied at all other times.

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