DISSERTATION

STRATEGIES FOR LIMITED AND DEFICIT IRRIGATION TO MAXIMIZE ON-FARM PROFIT POTENTIAL IN COLORADO'S SOUTH PLATTE BASIN

Submitted by

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ABSTRACT

STRATEGIES FOR LIMITED AND DEFICIT IRRIGATION TO MAXIMIZE ON-FARM PROFIT POTENTIAL IN COLORADO'S SOUTH PLATTE BASIN

Municipalities and other water providers are expected to seek increasing amounts of agricultural water to meet the demand to be created by projected future growth along the Front Range of Colorado and within the South Platte Basin. Farms often are acquired outright, the water rights parted off, and the decree changed to municipal use—a process commonly referred to in the regional water community as "buy and dry". Concerned about the negative effects of buy and dry on agriculture, rural communities, and even the environment, the State of Colorado has funded research into alternative, less permanent methods for transferring water from agriculture.

The purpose of this dissertation is to demonstrate through a simulation and optimization model that successful farming operations can be continued while agricultural producers benefit financially from a proportional parting-off of the water right. . Further, this dissertation will describe what an implementation embodiment of the technology described looks like operationally and as a practical matter.

Colorado water law allows transfer of only that portion of the water right which is used by the crop—its "consumptive use" (CU). Once the historic CU is

established and adjudicated through Colorado’s Water Court, the CU for that water right becomes a known quantity, thus allowing for comprehensive consideration as to how that CU water might be used to the owner’s economic advantage. Specifically, a future water use might be to continue farming but to lease or sell a proportion of the quantified CU water to a higher economic use – likely municipal or environmental interests.

This dissertation presents factors associated with the use of, and change in, water rights that may be considered by farmers interested in evaluating a package of changed farming practices intended to optimize future revenues. A future low-risk revenue stream may be brought into the farm’s revenue forecast by virtue of the lease of a proportional amount of water to a municipal, industrial, or environmental user. Optimization algorithms are used to evaluate a farmer-considered package of changed practices which may include: deficit irrigation, new crops, dryland crops, permanent or rotational fallowing of fields, and crop rotations. Some farmers will also consider upgraded irrigation systems as an aspect of implementing these practices. The farmer-driven optimization may include any or all of these changed practices as well as continued full irrigation of crops. To evaluate and compare multiple practices as a cohesive package and in the context of the option to lease water is new. The simulation and optimization model output assists in comparing historic practices and net returns with future practices and net returns which would include a revenue stream associated with a lease or sale of a proportion of the farmer’s CU water. The actual comparison between alternatives is accomplished by evaluating the change in net returns between historic practices and modeled future practices. The model utilizes crop water production functions, some of which are very newly researched and reported, to forecast crop yields based on deficit irrigation practices. The model can utilize up to 20 fields and 18 combinations of irrigation practices and crops. Up to seven deficit irrigation crops per field can be evaluated within a simulation and optimization scenario.

Recommendations are made for future research and software development that will incorporate the optimization routines into a larger collection of data inputs and a database intended to help farmers, ditch companies, or cooperative farmer groups manage their consumptive use water under a change decree and aggregated changed practices.

It is recommended that the ultimate and fully implemented system include:

- A package of technologies under one umbrella software program.
- A decision support system (DSS).
- A farm operations simulation.
- An optimization program for year-to-year evaluation of alternative farm operational strategies and potential for changed practices.
- A tool for evaluating a proportional parting off of consumptive use water.
- A means of developing and monitoring an annual water use budget.
- A database for cataloging historical and current operations of substitute water supply plans or change case decrees.
- A monitoring and reporting system for documenting the implementation strategy.
- A planning tool used year after year to plan pending annual operations against a farm or farmer cooperative total entity water budget.

Primary issues and pitfalls to implementing the process and strategies described are framed by these questions:

1. Can municipal interests view a long term lease as a viable part of their water portfolio and their projected safe yield at a future date?
2. Can farmers accept the perceived dramatic changes to their farming operations?

3. Can the science underpin the strategy sufficiently to satisfy change case objectors and the Colorado Water Court?
4. Can water be physically transferred based on existing water diversion and delivery infrastructure or is new infrastructure required in some cases?
5. Will farmers be interested in and accepting of a long term lease and might they also consider a buyout of the lease at a discounted net present worth?
6. Do existing State of Colorado statutes support the type of water transfer that is described?

Preface and Acknowledgements

It has been an absolute pleasure and a highlight of my career to do the work, accept the commitment, oversight the research and development, and proceed with the necessary discipline to research this problem and prepare this dissertation. The path has been long and somewhat circuitous. I started in the early 2000's with a wonderful opportunity to work on and support a CWCB-funded project at Colorado State University that examined secondary water supply systems (aka dual systems) as a means of providing water for landscape irrigation to growing municipalities. The co-principal investigators were Drs. Wilkins and Podmore. My own role was supportive but the opportunity involved the study of existing secondary supply systems in the western U.S. and the irrigation district tours and meetings that I attended with Dr. John Wilkins were wonderfully insightful. Thank you, John Wilkins, for your friendship, advice, and counsel.

The experience and work in secondary supply systems gradually led into further investigations and real projects in secondary supply feasibility studies, water rights, canal automation, SCADA, and new ways of thinking about all aspects of water delivery and water sharing. Those investigations and projects, along with the demise of Groundwater Appropriators of the South Platte (GASP), further led me into water rights investigations, historic consumptive use quantifications,

canal structural inventories, design of irrigation system improvements under NRCS's EQIP program, and other raw water delivery or irrigation operations experiences. Don Magnuson, the then manager of the Cache La Poudre Management Co., was involved in some of those projects and most of the investigations. Don has become my friend, confidant, and in some not-to-be-cited ways, a wonderful co-conspirator in consideration of new ways of looking at water sharing. Thank you, Don Magnuson, for your support and tremendous insights these past 10 years.

Through project work and engineering concept presentations to ditch companies, I attended more than 200 ditch company board meetings. Those accumulated meetings provided a wealth of practical knowledge in engineering, sociology, governance, and the reality of canal operations and management at the ditch company level. I would like to thank my own Louden Irrigating Canal and Reservoir Company board of directors for keeping me in line these past 10 years.

Now, as I am progressing along on this circuitous path as described here, my wife and former business partner is deep into conflict resolution, facilitation of meetings, and the sociology of how you attempt to get people to work together and cooperate on difficult water issues. I have learned much from MaryLou's experiences and I have been able to utilize many of her insights in my own work, including some aspects of this dissertation. Thank you to MaryLou Smith for your

insights and advice which were highly influential and much appreciated these past two years.

This dissertation is about intertwined interdisciplinary topics involving the fields of engineering, agricultural economics, sociology, law, and public policy. Per my Doctoral Committee’s recommendation, every attempt is made to appropriately put the dissertation’s emphasis on the engineering. I believe that goal is achieved as long as one includes the water rights, agriculture to municipal water transfers, and historic consumptive use topics as engineering topics. As Dr. Grigg has noted, “If engineers don’t do this work, who is? Engineers dare to see the big picture.” I am very grateful for Dr. Neil Grigg’s timely, contemplative, and insightful advice on the topics and the dissertation itself. Much appreciation and thanks is also noted due to Dr. James Pritchett and Dr. Jim Loftis for their critiques, comments, encouragement, and advice offered during the course of preparing this dissertation.

Although the simulation and optimization model (the Model) is most definitely defined by equations, this dissertation is not about equations. It is about a collection of technologies that can be brought to bear, under the current circumstance and the State of Colorado water policy and political climate, to encourage farmers to continue farming while taking economic advantage of the increased valuation of their water. Thanks to Dr. Lori Wiles for your tremendous

help with defining the equations in the Model and to Dr. Darrell Fontane for help in translating those equations into a useful Solver-based optimization model.

In the fall of 2009, I met Robert Stollar, Kevin France, and Ed Warner. They contemplated a new venture and a new company. The vision was to fund basic research, commission timely and needed software development, and package technologies that would help farmers first consider and then implement strategies to part off a suitable proportion of their quantified consumptive use water. Farmers would consider this in order to enjoy a new revenue stream while sustaining their farming enterprise. Together with these gentlemen, we founded Regenesis Management Group. My finalized dissertation topic then shifted somewhat to become one and the same with software and process development, the Model and the System, that we together envisioned.

Don Sanborn and I have worked together for more than 25 years. Don uses his agricultural engineering background to effectively develop databases, input screens, algorithms, and computer code that is functional, understandable, and useful. Thank you, Don Sanborn, for all those hours of great work over these many years.

Taken collectively, the technical elements described here plus the more recent work of researchers with the USDA’s Agricultural Research Service and in multiple departments at Colorado State University have provided me a timely and

unbelievably fortuitous opportunity to work on, benefit from, enjoy, and ultimately create a deliverable software program. The program and the technical processes have direct and immediate importance to the farming community on the South Platte. I am particularly indebted to Dr. Tom Trout, Dr. Gale Dunn, and Dr. Lori Wiles who are all with the Agricultural Research Service of the USDA.

This dissertation topic and the recommended next steps are coming to fruition even as the dissertation writing comes to a close. In the coming years, the benefits of this technology implementation will hopefully be observed and measured in terms of minimizing the amount of agriculture that comes out of production to support the inevitable water transfers to Front Range municipalities.

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CHAPTER 1
INTRODUCTION

1.1 Background

Many have spoken or written about water and the importance of water in our society, the Colorado region, the western United States, and the world. This well-defined importance ranges from the pure aesthetic attributes of water to the health and human safety aspects of water. The following quotes are intended to initially frame, in a very small way, the water topic and context of this dissertation.

> “Every human should have the idea of taking care of the environment, of nature, of water. So using too much or wasting water should have some kind of feeling or sense of concern. Some sort of responsibility and with that, a sense of discipline.”
>
> -The 14th Dalai Lama Tenzin Gyatso
> (Swanson 2001)

> We used to think that energy and water would be the critical issues for the next century. Now we think water will be the critical issue.
>
> -Mostafa Tolba of Egypt,
> former head of the United Nations Environment Program

> If surface water can be compared with interest income, and non-renewable groundwater with capital, then much of the West was living mainly on interest income. California was milking interest and capital in about equal proportion. The plains states, however, were devouring capital as a gang of spendthrift heirs might squander a great capitalist's fortune.
>
> -Marc Reisner (Reisner 1986)

> Anyone who can solve the problems of water will be worthy of two Nobel prizes – one for peace and one for science.
>
> -John F. Kennedy

It is hard to read, watch, or listen to any media during the last decade without hearing about the important and technically demanding topic of water. Water is in short supply generally, drought events may really represent climate shifts, clean drinking water is at a premium, water delivery infrastructure is aging, water no longer reaches the ocean on many significant rivers, the fish and the fowl are endangered for lack of minimum stream flows, farmers are often not getting a full supply of water when they need it for crops, and so on. Water is a prevalent and frequently addressed topic throughout the world with the generally underlying issues in agriculture being volume, quality, and timing.

A special report on water published by The Economist in May 2010 notes that:

> "The number of people on Earth rose to 6 billion in 2000, nearly 7 billion today, and is heading for 9 billion in 2050. The area under irrigation has doubled and the amount of water drawn for farming has tripled." (Grimond 2010)

The National Geographic Society published a special issue on water in the spring of 2010. One author noted that the myriad of world water issues facing us are not new, just different.

> "It is hardly the first time that water scarcity has created environmental refugees. A thousand years ago, less than 120 miles from modern-day Santa Fe, the inhabitants of Chaco Canyon built rock-lined ditches, headgates, and dams to manage runoff from

> their enormous watershed. Then, starting around A.D. 1130, a prolonged drought set in. Water scarcity may not have been the only cause, but within a few decades, Chaco Canyon had been abandoned. We hardly need reminding that nature can be unforgiving: we learn to live within her increasingly unpredictable means, we move elsewhere, or we perish." (Royte 2010)

These quotes illustrate the historical context of water problems, which are unfolding rapidly in the State of Colorado, In 2003, the State initiated a water resources planning effort called the Statewide Water Supply Initiative (SWSI) for the purpose of projecting water supply availability and needs for each of Colorado's river basins in 2030 (Gimbel 2010)[1]. Most basins in Colorado were found to be forecasting water shortfalls in 2030. For the South Platte Basin, shown in Figure 1, the SWSI report forecasted a population growth of 65% which equates to 2,000,000 additional people by 2025 and an associated water supply need of an additional 400,000 acre feet. The South Platte is already over appropriated. Transbasin transfers and new storage are essentially no longer feasible or extremely difficult options at best, because of permitting obstacles. The prevalent presumption within the regional water community is that the additional 400,000 acre feet will likely come from irrigated agriculture – water transfers from irrigated agriculture to municipal and industrial (M&I) uses (Colorado Water Conservation Board. et al. 2004).

1 It should be noted that the State-wide Water Supply Needs Update has recently been released in the Spring of 2011.

This population growth and water demand dynamic is also playing out in other states in the West and other basins in Colorado in the form of municipal acquisition of whole farms -- along with the water -- through outright willing-seller, willing-buyer purchases. The consumptive use (CU) portion of the water right is often 100% removed from the farm and the use of the water is most often changed to M&I use.

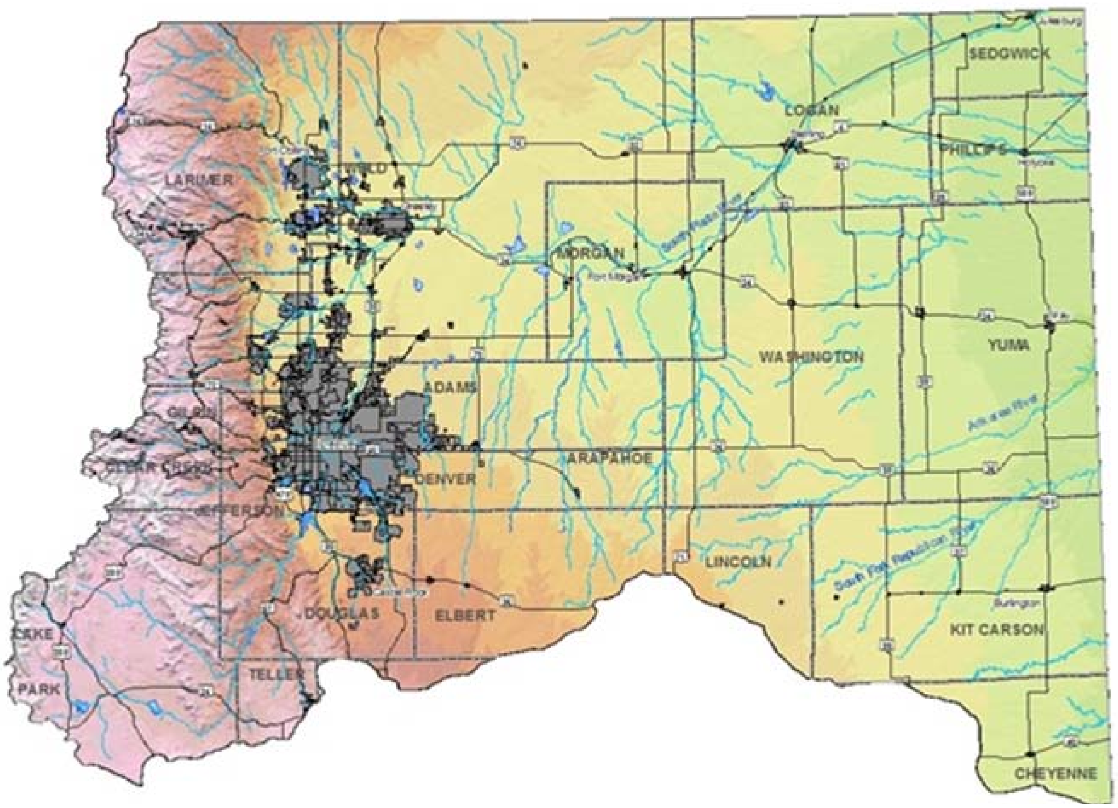

Figure 1. The South Platte River basin in northeastern Colorado (CDM 2006).

Sometime after the sale closes, the farm is dried up into perpetuity. This process of permanent dry up is often referred to as “buy and dry” in water planning circles and in the popular press (Gimbel 2010). Some of the municipalities who have availed themselves of this practice are now saying publicly that they do not wish to continue with the practice of buy and dry because of the impact on the rural community and the cumulative negative push back from many sectors (Montano 2010) and (MacDonnell 2008). At the same time, municipalities are actively looking for sound alternatives to buy and dry that provide predictable water supply, or “firm yield”, for the cities (CDM 2006).

The need to find alternatives to “buy and dry” drives this research and the following sections set the stage for the hypothesis of the study, which aims to find ways for farmers to stay in business and even improve their operations through a total approach to managing their resources.

1.2 Alternatives to Buy and Dry

Alternatives to buy and dry – also called alternative transfer methods (ATMs) – and often cited in the SWSI reports and elsewhere. They include:

1. Interruptible water supply agreements.
2. Rotational fallowing.
3. Water banking.
4. Reduced consumptive use through changed irrigation and farming practices.

The Colorado Water Conservation Board funded six research projects in 2009 that involved defining and offering credible options to “buy and dry” water acquisition. The $1.5m level of funding in 2009 is again brought to bear in 2010. This funding, along with the CWCB-created committee working on “alternative transfer methods" (ATMs), show clear evidence of the State's intent to bring forth new options or improve acceptance for those already being tested. In the fall of 2010, the CWCB allocated another $1.5m in funds and subsequently funded another six projects involving alternative transfer methods.

Interruptible water supply agreements involve temporary arrangements where agricultural water rights can be used for other purposes. Agricultural irrigation is temporarily halted under terms of an agreement in order to make a prescribed and contracted delivery (Trout Witwer & Freeman. 2004). An advantage of this approach is that an interruptible water supply agreement is defined by State Statute (37-92-309). It can be initiated under a contract arrangement between a water right holder (aka "water righter loaner") and a water user (aka "water right borrower") – likely a municipality -- needing water to cover a water shortfall in a given year. The statute confines the water transfer frequency to three out of ten years – hence strengthening the temporary aspect of this approach. The Colorado State Engineer is responsible for the oversight and approval of interruptible water supply agreements (Colorado Statutes 2003). Also, see Appendix 3 for the full text of two different Colorado Statutes that provide for water transfers between parties.

Rotational fallowing is conceived as a one to 10-year fallowing arrangement where, for instance, a fraction of the participating farms in a mutual irrigation company or other entity agree to fallow their farms, and thereby transfer a predetermined amount of water to a municipal interest (HDR Engineering 2007). Fallowing involves closely prescribed reseeding and establishing a suitable grass cover to protect the fallowed ground from erosion.

Water banking is a Colorado legislature-authorized approach to storing or setting aside water so that it can be leased to an alternative need during drought or when the water would otherwise not be put to beneficial use (Gimbel 2010). A water bank was initiated and exists in the Arkansas Valley. However, to date, it has not received enough user acceptance to make it truly viable.

Reduced consumptive use through changed farm water management involves identifying a quantified portion saved from the historic crop CU on a farm or farms. This saved portion of the CU would then be parted off and moved toward non-farming beneficial uses. The remaining historical CU would be used to continue agricultural operations. Ideally, this process would be carefully planned and monitored to ensure future farming operations (Colorado Water Conservation Board. et al. 2004), (Gimbel 2010), and (Smith 2010).

This dissertation focuses on the fourth ATM option noted previously, namely reduced CU through one or more changed farming practices. In Colorado, there are currently two examples of reduced consumptive use under consideration that are at varying stages of development and adaptation.

Canal Company Joint Endeavor

In the Arkansas Basin of southeastern Colorado the concept of reduced consumptive use is exemplified by the idea of a Super Ditch Company (Gimbel 2010) and (Woodka 2009). The Super Ditch is a recently formed, for-profit farmer-managed entity that represents the collective interests of seven ditch mutual irrigation companies by offering a rotational fallowing option to constituent farmers (HDR Engineering 2007) and (Nichols 2010). In many ways, the Super Ditch Company is a farmer cooperative. The Super Ditch may enter into a contract with a municipality to annually deliver a prescribed amount of CU water over a specified period of time. The CU water is made available through rotational fallowing on irrigated lands within the service areas of the respective ditch companies participating in the consolidated entity represented by the Super Ditch. Currently, the Arkansas Valley's Super Ditch Company has only implemented rotational fallowing as a change practice. Farmers can evaluate a number of fallowing options suitable to their specific circumstance. They then make it known to Super Ditch management that some proportion of their irrigated land is available to be fallowed.

Some operational issues are still under consideration, and as of mid-2010, no "wet water"[2] has been delivered under contract. However, according to published newspaper reports in the Pueblo Chieftain, a letter of intent to contract has been executed between Super Ditch and the Pikes Peak Regional Water Authority

2 The colloquial term "wet water" is often used when referring to actual water diverted and delivered in a trade or acquisition as opposed to a paper transfer of water.

(Woodka 2009). Further, a proposed lease arrangement between the Super Ditch and the City of Aurora was most recently announced. This involves buying up to 10,000 acre feet from Super Ditch farmers at a price of $500 per acre foot per year for any three years in a 10-year period (Pueblo Chieftain 2010).

Peter Nichols, the lead water attorney for the Super Ditch reported in a July 16, 2010 memorandum to the Colorado Water Conservation Board that

> "It appears that the costs and time required for legal, engineering, and accounting under a 'business as usual' approach to a rotational fallowing change case may become cost prohibitive to the irrigator-lessors. The ultimate conclusion is the time required to put together a program, negotiate leases, and resolve contingencies will delay and possibly kill fallowing-leasing."

This insight highlights the transaction costs that can be incurred by a water right holder in securing this kind of contract agreement with a municipality of other entity (CDM 2010).

Individual Landowner Endeavor

A somewhat different approach to the joint endeavor represented by the Super Ditch in the Arkansas Valley, is in the early stage of program development, research, and vetting within the South Platte Basin. In this approach, which is central to this dissertation, farmers initiate their own desktop computer analysis of their farming operation (a simulation and an optimization using linear programing). They evaluate future "what if" operations, and consider the cumulative effect of multiple changed farming practices. Such an analysis facilitates viewing their CU water as a farm asset and a CU water budget, from which they then evaluate an incremental parting off of some portion of their CU. In other words, the objective is to assess how this economic asset can represent a potential revenue stream for the farm operation, by way of leasing a portion of their CU water.

The lease of a proportion of the CU could become a steady and more predictable (low risk) revenue stream for the farmer over the term of a lease. By evaluating alternatives which may include a full package of changed farming practices, the farmer can at least evaluate the potential for adaptation of this new technology. Does it work financially and practically or not? What is the threshold value of CU water needed to make this option potentially attractive for the farm operation? Of course, the answer to such important questions is an individual decision, but at least the option can be fully evaluated using the envisioned program decision support system (DSS). Changed farming practices represent a business decision, of necessity, but a decision best underpinned by sound engineering and economics (HDR Engineering 2007).

1.3 The South Platte River Basin Circumstance

The South Platte Basin has become a focus and “poster child” of many of the interrelated problems associated with population growth and the municipal hunt for growth-driven water supplies. Cities and towns along the Front Range have varying water portfolio amounts in what is commonly referred to as “safe yield” water to serve their growing populations to a prescribed date in the future. The time period for evaluation of safe yield is generally 50 to 100 years.

There is often a “desperation mentality” in play that forces municipal water managers to grasp at all alternatives – conservation, new storage, leak detection, fines for water wastage, water conservation programs, public information programs, and aggressive water acquisition. In the water acquisition realm, the City of Thornton clandestinely bought up northeastern Colorado farms in 1986 with the explicit purpose of eventually drying up those farms and moving water south to Thornton for future water supply needs (The Denver Post 1994). This approach creates a lot of angst, distrust, and uncertainty in the water community; not to mention the community at large. In addition, periodic drought conditions and climate change discussions further magnify this “desperation mentality.” As noted in Colorado Water Conservation Board’s 2004 SWSI report:

> “Nearly two-thirds of the increase in the state gross demand by 2030, approximately 409,700 AF, will be in the South Platte Basin. Of the 409,700 AF of increased water demands in the South Platte Basin, the majority of the demand is proposed to be met through existing supplies and water rights and through the implementation of identified projects and processes. However, there are still some anticipated shortfalls expected in certain portions of the basin. The identified shortfalls will be the focus for supply alternatives developed for the basin.” (Colorado Water Conservation Board. *et al.* 2004)

Todd Doherty, program manager with the Colorado Water Conservation Board, noted in a recent Colorado Water issue that “most of the demand (water for population growth) will be met through three main water supply strategies:

conservation, agricultural transfers, and new water supply development." He goes on to say that "if these new water supply projects are not built, future water demands will have to be met mostly through a combination of agricultural transfers and conservation" (Doherty 2010).

In a recent U.S. congressional hearing, Jennifer Gimbel, Director, Colorado Water Conservation Board, offered the following expert testimony:

> "The projected growth in the South Platte River basin will create water supply challenges for the agricultural community. The basin currently irrigates approximately 830,000 acres. Since 2001, the basin has seen a decline of approximately 100,000 irrigated acres due to well curtailment, urbanization and urban transfers. The basin will likely lose 40,000 to 50,000 acres as a result of urbanization. An additional 160,000 to 280,000 acres is expected to be lost due to agricultural to municipal transfers--combined this could equate to a 25% to 40% reduction in its irrigated acreage in the basin by the year 2050. There are several projects working through the federal permitting process that could assist in helping to minimize the loss of irrigated agriculture. Those projects include Halligan-Seaman Project, Moffat Collection System Project, Windy Gap Firming Project, Northern Integrated Supply Project (NISP) and Chatfield Enlargement Project. However, comments from the Environmental Protection Agency suggest that agriculture dry-up is the least environmentally damaging alternative to most of the proposed projects. This conclusion ignores the environmental benefits of the irrigated acreage itself, as well as the return flows, riparian environment and wetlands that are created"(Gimbel 2010).

Clearly, water to serve the population growth anticipated in the South Platte is going to be a significant issue over the next two decades and beyond.

1.4 Evapotranspiration and Consumptive Use

Evapotranspiration (ET) refers to the combined processes by which water is transferred from the earth surface to the atmosphere; evaporation of water plus transpiration from plants. Consumptive use (CU) is the total amount of water taken up by vegetation for transpiration, plus the unavoidable evaporation of soil moisture, snow, and intercepted precipitation associated with vegetal growth (Jensen et al. 1990). Reference ET, commonly abbreviated ET_o, and also known as reference crop ET, is the evapotranspiration rate from a reference surface not short of water. The reference surface is a hypothetical grass (or alfalfa) reference crop with specific characteristics. The terms are graphically depicted in Figure 2 which is extracted from (Allen et al. 1998).

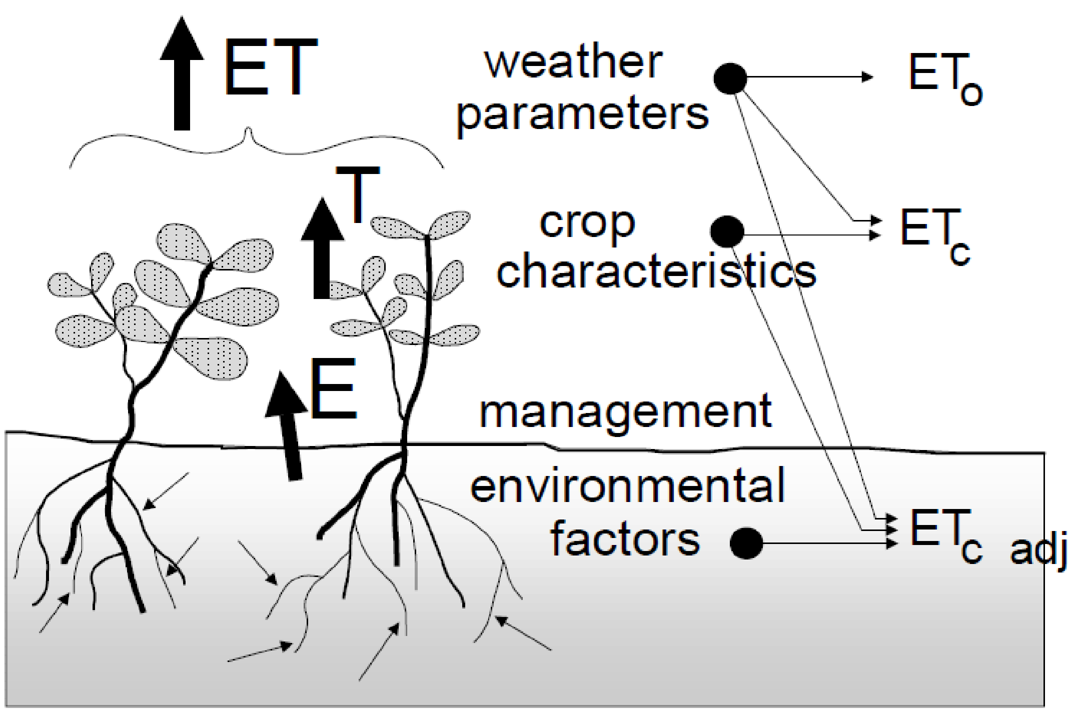

Figure 2. Factors affecting ET and references to ET related definitions.

The two terms, ET and CU, are quite closely related, but defined differently and for differing purposes or discussion reasons. In this dissertation, these two terms will be characterized and utilized as follows:

1) ET is the preferred and more correct term when one is discussing the reference ET rate or ET rate for a specific crop when the purpose is to schedule irrigations with sound knowledge of the crop's seasonal water requirement. The most common English units are inches per day, which is a rate of use. The term evapotranspiration is commonly used in farming and engineering practice.

2) CU is the preferred and more correct term when one is discussing the total amount of water that is removed from the system, usually on a monthly or yearly cropping basis, as water is put to beneficial use. The most common English units are acre feet, which is a volume of use. CU often represents a total volume for all the crops on a farm or all the crops under a ditch system, or all the crops and water consuming plants in a hydrologic basin. The term CU is commonly used in water resources, water rights adjudication, and detailed definitions within a water decree.

There are multiple approaches and named equations for calculating ET, and the equations and calculation methodologies are quite thoroughly documented in the technical literature. The literature is filled with a wealth of background on evapotranspiration and the use of ET rate equations for the estimation of consumptive use. For the narrow perspective and purpose of this dissertation, it should simply be noted that there are two ET rate equations that are in common use and prevalent over time in water rights change cases in the South Platte Basin.

The Blainey-Criddle equation was the most widely known and used method from 1945 and into the 1970s. This method was widely adopted because the climatic data needed was readily available from most U.S. Weather Bureau weather stations and it was widely considered valid and accurate for monthly calculations of ET (Jensen 2010).

The Penman-Monteith equation is considered “modern” in that it is widely thought to represent the best science in this specific technical arena. It can be used for prediction of the reference ET rate over short periods of time, even one hour. A limitation is that the climatic data needed must include solar radiation and some weather stations, especially those weather station sites installed prior to 1970, which did not include a pyranometer for solar radiation measurement. The Penman-Monteith equation is also widely referred to as the ASCE Standardized Equation because, in the late 1990’s, the Irrigation Association requested that the ASCE ET Committee recommend a single procedure for estimating reference ET in the U.S. Subsequently, an ASCE task committee developed such a procedure as described in 2000 and published in 2005 (Allen and ASCE / EWRI Task Committee 2005).

One additional detail on these two ET equations is important within the context of this dissertation, and also relative to the South Platte Basin. The historic consumptive use estimates in many adjudicated change case decrees in Colorado used the Blainey-Criddle equation as the basis for the engineering study and the estimate of ET. More recent engineering studies for more recent change case decrees tend toward using the Penman-Monteith equation (aka ASCE Standardized Equation) because, as noted, it is considered to be more accurate and valid for short time periods. Consequently, water decrees in Colorado often have differing ET rate equations as their basis. One equation might have been used in a previously adjudicated change case, while engineers or attorneys involved in a subsequent change might recommend changing the method later on without a clearly defensible reason. It is also generally recognized that the Blainey-Criddle equation tends to result in a lower value of ET, as compared with the Penman-Monteith equation, and given identical climatic data sets.

Another point is important in this context and relevant to final decree negotiations. As engineers support the lawyers on behalf of a client as a change case proceeds, there are many technical details that come into play. During the process, engineers will argue over technical details that often represent somewhat subjective or esoteric dimensions of the engineering. It has been observed that in the final negotiation of a change decree, the technical merits will be set aside in order to complete the negotiation, the goal being to encourage the objector to agree (stipulate) to the wording of the final decree. In other words, subjective aspects of the negotiation can trump the scientific argument.

1.5 Establishment and Quantification of Historic Consumptive Use

In order for a water rights transfer to take place in Colorado, the historic CU for the water right must be analyzed and ultimately adjudicated in Water Court. There is no intent here to fully describe the combined engineering and legal process of formally establishing the consumptive use of a water right in Colorado. However, for the purpose of framing a Colorado Water Court change case effort, which requires a study of historic CU, it is worthwhile to describe pertinent aspects of the process.

To begin, (Pease 2010) notes these overview requirements about water rights transfers:

> Often a transfer of water has unknown impacts on downstream users, or at least an impact that is difficult to quantify. A water right should contain the following information:
>
> - a diversionary amount
> - a consumptive amount
> - the point of diversion
> - the purpose of use
> - place of use
> - the priority date of the right.
>
> Also important, but often omitted from water rights are, the time of year during which water can be diverted from a water course, and the size and location where return flows reenter the system. A change in any of these attributes can negatively impact downstream users.

Figure 3 illustrates these principles. The four corners of the rectangle defining the water right are type of use, place of use, point of diversion, and season of use. If any one of these corner attributes is vetted for change or changed, the water right comes up for scrutiny, resulting in a change case in Colorado's Water Court.

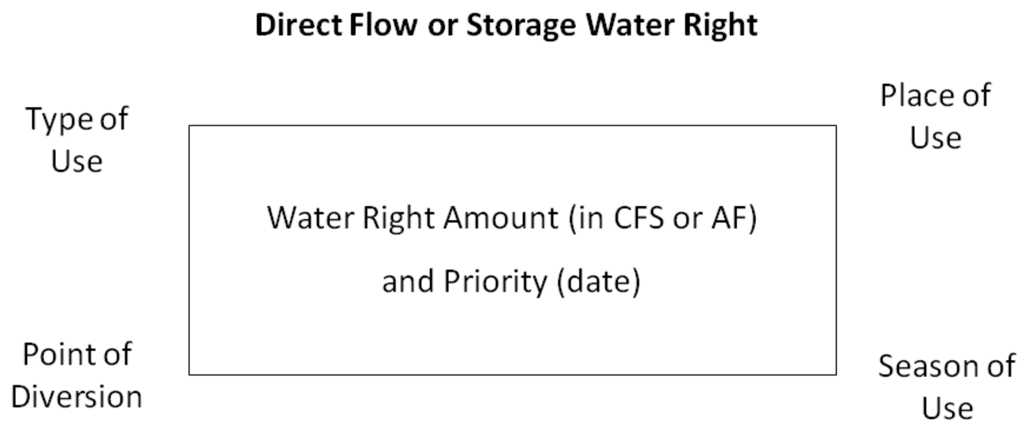

Figure 3. Water right attributes which, if changed, could force a change case.

As a very simple example, consider two 500-acre farms with different water rights. The first farm has been historically irrigated with 3,000 acre feet of water diverted from the river, while the second farm has been irrigated with 2,000 acre feet of water. Both farms utilize the same surface water right. Both farms have historically grown fully irrigated corn. Let us further assume that the CU for corn is 2 acre feet per acre, or 1,000 acre feet for either of these 500-acre farms. Notice that the CU for each farm is, in fact, identical despite their different historical diversion of water. However, the first farm that diverted 3,000 acre feet returns more water to the river than the second farm, either as surface return flows or a subsurface return flows. In short, the consumptively used water is the same in either case, considering their irrigated area and crop being the same. In other words, the CU portion of their water right is identical. Understanding this distinction is becoming much more common by all the segments associated with water rights acquisition, management, or administration in Colorado. Understanding this often overlooked dimension of consumptive use is also key to understanding the purpose and value of the technology described in this dissertation.

There is yet another important dimension to CU, and it has to do with the potential consequences for other irrigators sharing a mutual irrigation company water decree when the adjudication of CU is conducted for any individual farm. Let it be first noted that if farmers have beneficially used a water right decreed for irrigation for a long period, then they can continue to use the water right in that way indefinitely with no need to define or quantify historic CU. With that said, an evaluation of CU is generally driven by a change in the type of use, place of diversion, or the quantity of water diverted, as highlighted in Figure 3. Let it further be noted that because the engineering to establish historic consumptive use is time consuming and therefore costly, it is unlikely that anyone would take on the effort without justification. However, it is important to note that the determination of CU on one given farm change case could be construed by the adjudication process as representing a "ditch-wide analysis"[3] and therefore affecting all the shareholders of that mutual irrigation company, whether they actually participated in the change case or not.

3 The term "ditch-wide analysis" is often used in referring to a Colorado Water Court change case which fully encompasses the historic service area of the ditch company.

1.6 Ditch-wide Versus Small Parcel (Share Block) CU Analysis

An historic consumptive use analysis can be accomplished for, (1) a single parcel of land (potentially a single shareholder), (2) a subset of the full shareholder group in a parcel specific analysis, or (3) it can be done for the full service area of the Company, which is referred to as a ditch-wide analysis (Magnuson and Smith 2010).

In a case commonly known as the "Jones Ditch Case" (See *Re Water Rights of Central Colorado Water Conservancy District,* 147 P.3d9 (Colo. 2006), the Colorado Supreme Court stated that a ditch-wide analysis is preferred. Unfortunately, the court did not elaborate as to why a ditch-wide analysis should be preferred. Even though that decision appears to leaves considerable room for speculation and future litigation, all of the three above-mentioned approaches for calculating historical CU would appear to be legally valid.

The underlying issues between the three approaches are exemplified by the histogram depicted in Figure 4. At some time in the distant past, as with many ditch companies, there might have been an initial and limited distribution of shares for a given acreage of land. Over time, especially over a 100-year plus timeframe, some farmers may have sold shares and others may have bought shares within the ditch company's service area. This is actually quite normal, and represents a perfectly legal and acceptable means of selling and buying shares within a mutual irrigation company – a transaction between a willing seller and a willing buyer, usually with very low transaction costs. The reasons for the movement of shares within the company are numerous, but such exchanges were more than likely driven by one shareholder's need to sell an asset to raise cash and another shareholder's desire to increase their water holdings. The important point here is that some farms, through this process of buying and selling over the years, can become water short, or conversely, water long.

Figure 4 shows an example of the disparity that can result from this process over time. If a ditch-wide analysis were assumed, the average historical consumptive use for this example would be 27.5 acre feet per share. By contrast if a subgroup of water short shareholders initiated a change case, then their quantified CU per share of water in the company would be proportionally greater per share than if a group of water long shareholders initiated a change case. In other words, fewer shares irrigating the same land and the same crop would result in a greater burden on those shares when the CU was quantified. Variations might be due to a number of factors, but some of those factors are:

1) Differing engineers or legal counsel with the change cases.
2) Different period of record.
3) Specific farming practices associated with the shares in question.
4) Discovery of differing cropping records.
5) Differing periods of record.
6) Actual measurement of factors such as canal seepage versus assumptions.

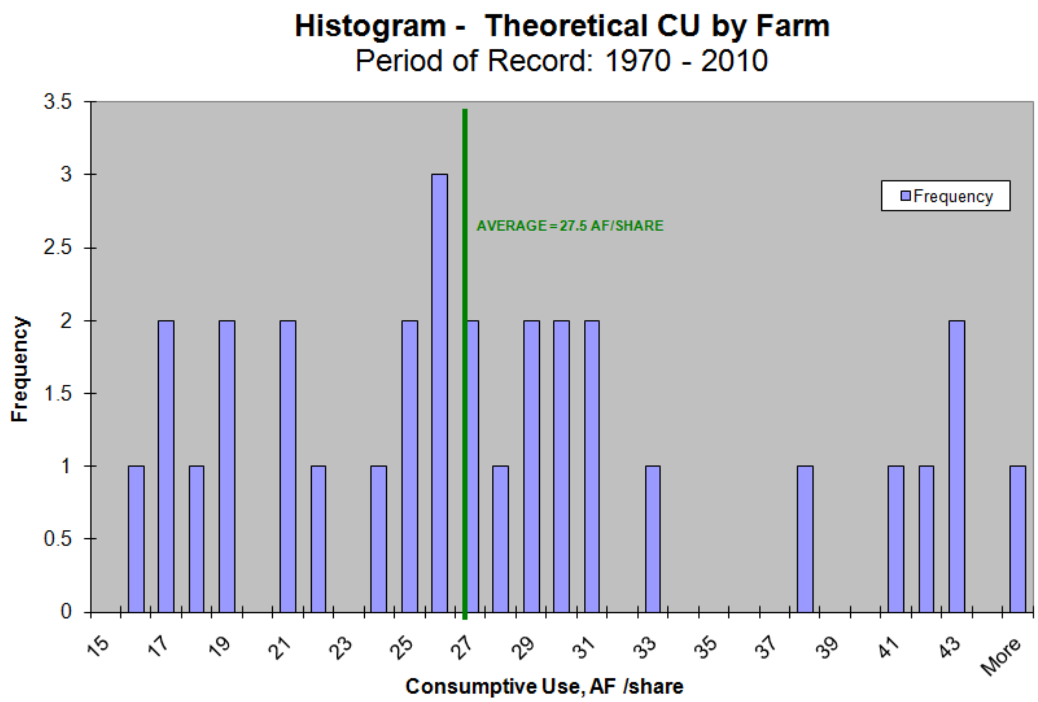

Figure 4. A histogram depicting the theoretical variability possible in share ownership under a single ditch system.

Table 1 summarizes important reasons why a ditch company shareholder perspective (or ditch-wide analysis) is often preferred over a parcel-by-parcel analysis. From a mutual irrigation company perspective, a stockholder owns a pro rata interest in the company's water right (decrees). The stockholder pays a pro rata portion of the operating expenses of the canal system through annual assessments. So, why would company stockholders have anything other than a pro rata interest in the ditch-wide; given that such an approach to CU analysis is consistent with the company's historical service area water use?

Table 1. Comparison of Parcel Specific versus Ditch-wide CU Analysis

PARCEL SPECIFIC ANALYSIS	**DITCH WIDE ANALYSIS**
CU varies from parcel to parcel (share to share in the company)	CU is equal (quantified and standardized) for every share
Dry up acres vary for every parcel or share (but limited to parcel involved)	Dry up acres equal for every share
Cheaper analysis short term	Market develops for surplus dry up acres
Exposes stockholders to multiple inaccuracies from different sources in differing analyses	More expensive analysis short term
Often done using river diversion record and not headgate deliveries	Opens system to easier changes in the future
Favors those with fewer shares per acre	Favors those with fewer acres per share
Favors those who improved irrigation facilities (if they increased the acres irrigated)	Favors those who paid the expenses historically
Favors those who sold off water	
Shareholders may not be aware that a parcel level change may affect their CU per share	All shareholders are informed and participants in the change case
Requires the company to be involved in multiple analyses with multiple engineers and attorneys.	More indicative of the intent and spirit of a mutual ditch company

In contrasting a parcel-specific analysis of CU with ditch-wide analysis of CU, and with particular reference to this dissertation, the summary points are as follows:

1) The selling of shares by any individual stockholder has the potential to adversely impact other company stockholders, if not properly approached. In addition, a precedent could be set by an individual landowner's change case that could have unintended consequences to others.

2) There are pitfalls with either approach if you view the question from strictly the point of view of the water long versus the water short shareholder.
3) A more magnanimous approach in asking “what’s best for the irrigation mutual company as a whole?” is probably preferred from the Company’s perspective.
4) A ditch-wide analysis is preferred if shareholders are to come together as group, a cooperative for example, to consider proportional CU leasing to municipalities.

A ditch-wide analysis of historic CU is preferred for a ditch company or farmer cooperative that is interested in implementing the technology and operational system described in this dissertation.

1.7 The Historic Record and Water Balances

The estimation of CU can be complex and time-consuming. The historic water diversions (water measured through the company’s river diversion) and season of use can generally be found in the data base of the South Platte Decision Support System (http://cdss.state.co.us/DNN/default.aspx). However, historic cropping data and irrigated acreages are not so easily found, resulting in the need for background engineering investigations. One must usually investigate vintage aerial photography from multiple sources, and covering multiple years. Efforts must be undertaken to locate and check publically available Farm Service Agency documents and records. Often, landowners and irrigators must be interviewed, resulting in a time consuming effort to understand past water uses. Often, the ditch company's living board members and board or annual meeting minutes can provide useful historic information. Historic irrigation practices, estimates of irrigation efficiency, and delivery efficiency (canal seepage) also come into play with the CU calculations and must be determined or estimated from available records.

This process has been facilitated by the Integrated Decision Support Consumptive Use (IDSCU) model that was developed at Colorado State University for the purpose of assisting engineers and attorneys in the development of databases and the calculation of historic ET. Essentially all of the methods and equations for calculating ET can be evaluated and compared when using the IDSCU model (Garcia 2009). In recent years, this model has been almost exclusively used by water resource engineers in Colorado Water Court change cases.

A water balance of the river, canal, or the farm is a useful means of understanding the sources of and the destinations of water. Figure 5 provides a conceptual rendering of water balance analysis, from the river diversion downstream to the on-farm distribution system. Basically, what this illustrative graphic shows is what happens to water once it is diverted into a ditch or canal for irrigation purposes. In many ditch company operations, the character of the water changes significantly as one moves downstream in the canal. Colloquially, some would say that the “color” of the water changes; a reference to where the water came from, or where it is bound, or its decreed use.

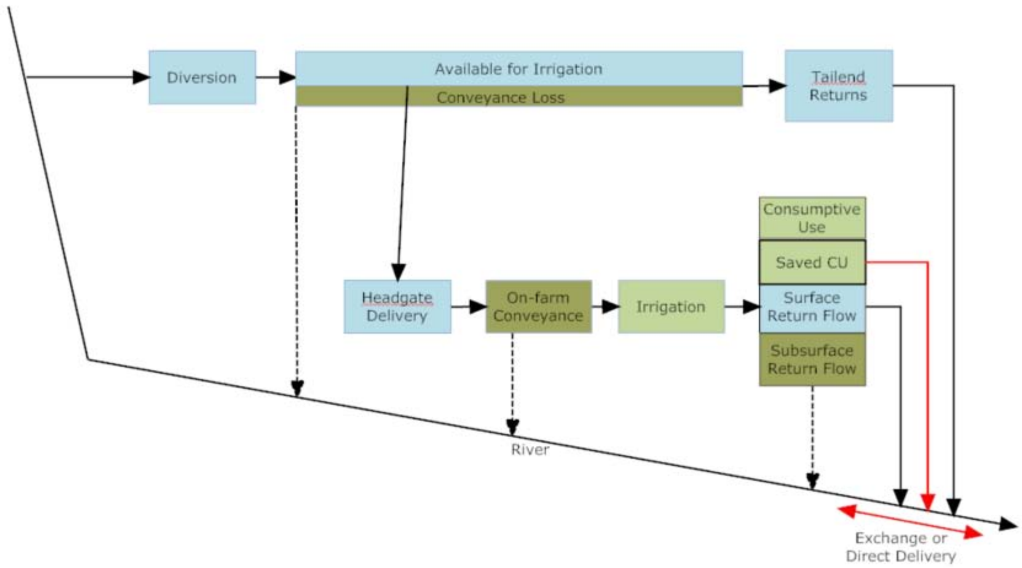

Figure 5. Depiction of the elements of surface water delivered to the farm via canal.

After diversion into an earthen canal, the diverted flow immediately begins to diminish because of conveyance losses, the most notable of which is seepage. Other losses are attributable to phreatophytes and evaporation from the water surface. Seepage can be quite significant especially over the full length of the canal and is likely the single highest source of loss in earthen canals. Most seepage returns to the river as subsurface flows and the time it takes to actually arrive at the river is a function of distance from the river and the characteristics of the alluvium (Topper et al. 2003). This seepage can vary considerably over the length of a canal as well. With a water right change case, this historic subsurface return flow pattern must be maintained into the future[4].

Moving downstream through the canal, some water returns to the river via the end of the canal as wastage or operational spill. Some canals have historically diverted a generous amount of water to assist with practical canal operations. It is easier to deliver equitable flows to canal headgates, especially those at the end of the canal, if the canal is flowing nicely with excess water that can be returned to the river for other downstream users.[5]

Continuing reference to Figure 5, a headgate delivery to the farm has similar water balance characteristics as with the main canal. However, the headgate delivery frequently represents the point at which the company's delivery responsibility ends and the individual farmer's responsibility begins. Downstream of the farm headgate, there are often on-farm conveyances (ponds and delivery ditches) from which there are losses, and again, those loses are most notably seepage.

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4 When return flows must be maintained as noted, there is something of an irony that should be mentioned with canal seepage and other delivery system efficiency improvements. When a canal has seeped for 100 years are more, the seep flows migrate to the river or into drains, wetlands, or tributary streams. These accumulated flows are then re-diverted by other downstream water users and those waters are often the basis of, or at least a portion of, someone else's water right. So, it can be argued that lining or piping a canal would lead to injury to the water rights of others by confining what had been seep water to the canal itself for delivery to ditch company shareholders. In essence this may constitute an expansion of a water right.

5 This practice is becoming less common as canals come under scrutiny for "sweeping the river" (diverting the full flow of the river) even if they are decreed to do so.

Once water is delivered to on-farm irrigated fields, and on through the associated farm irrigation systems, the key elements of irrigation water can be identified as consumptive use, surface return flows, and subsurface return flows. Within the consumptive use amount, there is a proportion that may be appropriately termed "conserved" or "saved" or "set-aside" CU. This amount is the water that might be considered for its higher economic value[6]. The total amount of quantified CU can be evaluated in terms of a water budget. The CU volume can be considered, along with old or new proportional uses, and within the confines of the water budget.

The average historically diverted water to the farm can be characterized as consumptive use, surface return flow, and subsurface return flow (Figure 6). Crop consumptive water use is the amount of water transpired during plant growth plus what evaporates from the soil surface and foliage in the crop area. The portion of water consumed in crop production depends on many factors, including whether or not the availability of water is limiting evapotranspiration. Additionally, CU varies with soil texture, crop varieties, and so on.

Once an estimated or a fully decreed consumptive use is known for a given water right, it opens up the potential to consider options for how the CU might be

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6 With regards to economics and the "higher economic value", Hoffmann, S. J. (2009). *Planet water : investing in the world's most valuable resource*, John Wiley & Sons, Inc., Hoboken, N.J. discusses water valuation in the context of a human right and a commodity versus water as a natural resource and says "My view is the human right to water trumps the "invisible hand" of the free market, but, at the same time, elevating water to a human right must not paralyze what needs to be done to achieve water resource sustainability. And the fact is that sustainability requires an element of market influence."

utilized differently in the future. This could involve addressing differing demands and, for that matter, market forces. The consumptive use could be allocated to a new use priority or some balance between old and new priorities. The consumptive use can now be viewed more rationally as an on-farm CU water budget with potential alternative uses. Obviously, and in point with the overall premise of this dissertation, a new use of the CU might be to portion off some of this “set aside” CU to a municipal or environmental water user for suitable monetary consideration.

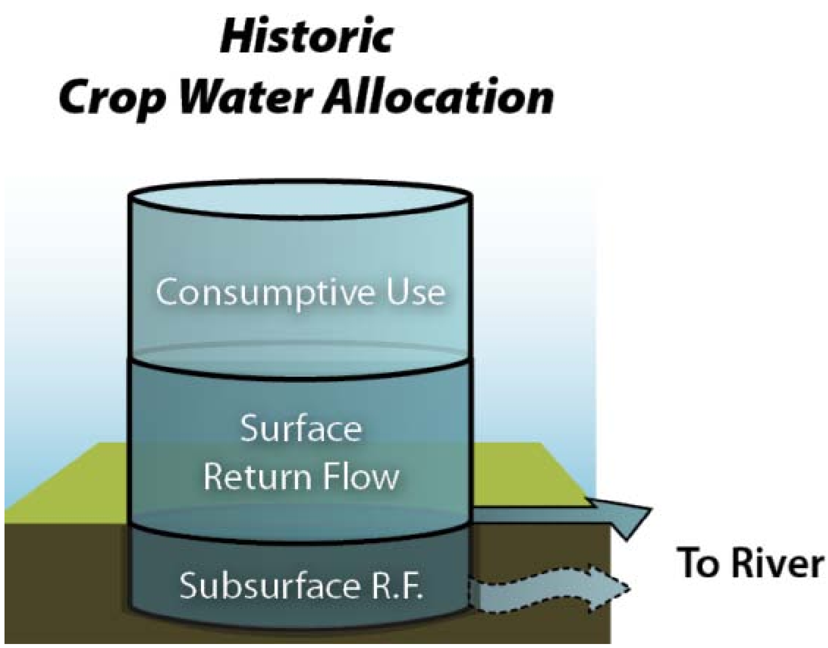

Figure 6. Depiction of the primary named use of water in a water balance on the farm.

As a simple example, consider a farming operation that is typified as follows:

- 150 acres irrigated.
- Owned surface water supply of 10 shares in a ditch company that, on historic average, delivers 30 acre feet per share or 300 acre feet total.
- The CU has been established via a ditch-wide analysis of the shares and the water right. The decreed CU is 10 acre feet per share or 1/3 of the average annual yield.
- A local municipality is offering $500 per acre foot of CU water on a long-term lease arrangement.

In this example, the farmer has 10 shares times 10 acre feet per share or 100 acre feet of CU water available in an average year. Possibly the farmer wants to consider parting off half of that water, or 50 acre feet of CU water, in consideration of a lease. A lease of the water to a municipality would provide a low risk revenue option and a predictable revenue stream ($25,000 / year) into the farming operation. Note that the value of $500 per acre foot of CU water is a value being used in a proposed lease agreement between the Super Ditch and two water user entities -- the Pikes Peak Regional Water Authority (Woodka 2009) and the City of Aurora (Pueblo Chieftain 2010).

Planning for the use of the remaining 50 acre feet of CU water can now be considered by the farmer. Planning must include appropriate consideration of each component of the water right. Historic return flows must be maintained, and this applies to the full historically diverted water right, as if no CU water had been parted out. Using this approach, farms can change their irrigation practices with this remaining CU, be operationally changed in other significant ways, such as converting to dryland crops or fields fallowed to further reduce the amount of CU water that is used. Monitoring and reporting requirements of such operational changes are likely to be precisely mandated in any change case decree. The State of Colorado Dept. of Natural Resources has become much more stringent in the last decade, requiring more timely, even real time, data to support administration and monitoring requirements of changed decrees (Belt; 2010).

It is important to note that a lease to a municipality probably includes a guarantee for delivery of a certain amount of water each year. This would be defined in lease agreement and contractual terms, but would likely be a commitment to deliver an agreed upon amount of water regardless of the impact on the farming operation in that year. In other words, the farmer would seemingly be required, under contract, to accept and deal with any water shortage in any given year. A drought year, or a sequence of drought years, could result in it being necessity for the farmer to deliver the agreed upon amount of water regardless of the impact to the farming operation. Severe drought conditions might result in curtailing farming during drought years so as to meet the contractual obligation to the municipality.

A somewhat broader view of this circumstance is shown in Figure 7. It indicates surface irrigated fields, and again identifying the “color” of or designations associated with the water. Downstream of the river diversion the canal seepage contributes to return flows to the river. After water is diverted at the farm headgate, water flows down furrows and the portion that does not infiltrate to the soil becomes tailwater and returns to the river as surface return flows. Deep percolation below the crop root zone is subsurface return flow.

Flow measurements are indicated in Figure 7 at the river diversion, downstream of the farm headgate, and on the tailwater return ditch. In the past, some or all of these flow measurements were not necessary and not undertaken due to hydraulics structure costs and data collection costs. In the future, and under a substitute water supply plan, an interruptible water supply agreement, or a water right change decree, all of these flow measurements will likely be required along with timely and transparent reporting (Belt; 2010).

It is envisioned that the planning and optimization aspects of this dissertation, referred to here as the “Model”, will eventually become part of a bigger operations modeling, implementation, data collection and reporting scheme, referred to here as the “System”. A decision support system of this scope is envisioned and needed because of the likely monitoring and reporting impositions that will be part of a water rights change case and decree. This need will be described in Chapter 5 of the dissertation. Furthermore, the Colorado State Engineer may require certain details, timely (even real time) reporting, and submission in accordance with the decree, in order to ensure Division of Water Resource staff oversight.

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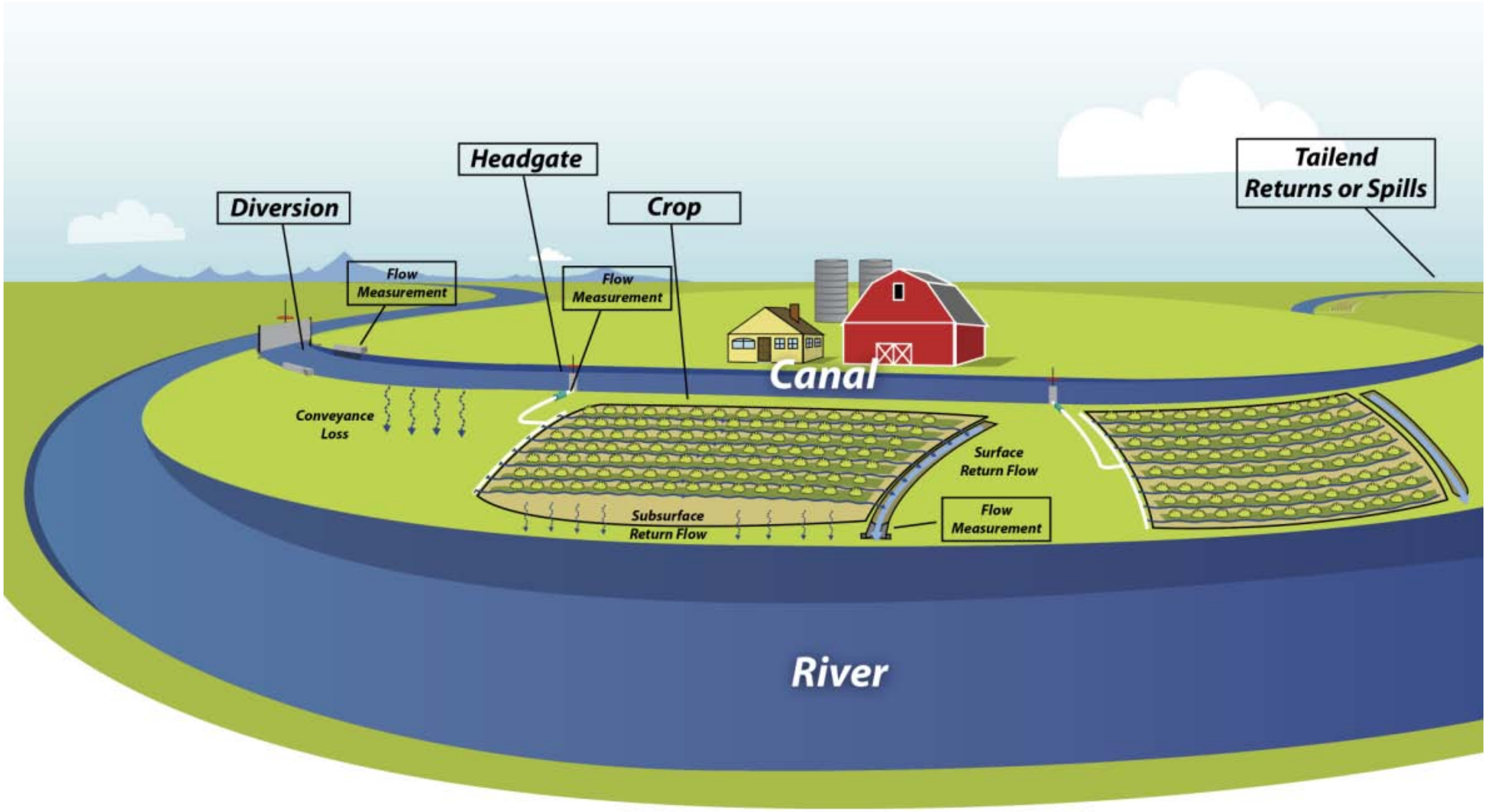

Figure 7. A graphic depiction of a river diversion, canal, and elements of on-farm water delivery and return flows.

1.8 The Hypothesis and Objectives

To establish the hypothesis, it is good to review some key points. First, it is clear that water resources in the South Platte Basin are currently over appropriated. Second, a significant amount of the water to sustain the anticipated and continued population growth in the basin is likely to come from agriculture in one way or another. Third, many observers are not viewing so-called “buy and dry” options as a suitable method of obtaining municipal and industrial (M&I) water, primarily because of the tremendous negative impact on rural communities. Fourth, and central to this dissertation, alternatives to “buy and dry” may be attractive to those acquiring future water supply as well as those currently owning water rights.

The hypothesis is as follows:

An optimized package of irrigated farming practices based on a consumptive use water budget can demonstrate the feasibility of selling or leasing a fraction of a water right to make farming more attractive, profitable, and sustainable.

To evaluate this hypothesis, the primary objectives of the study are to:

1) Define and build a body of background knowledge and perspective of the topic with emphasis on the agriculture to urban water transfers that are occurring throughout the west, and in particular, the South Platte Basin.

2) Define farm operational assumptions to include likely annual starting conditions and changed practice adaptations as a package that have merit to farmers.
3) Define production costs, probable yields, and water lease revenues as model input variables and include suitable ranges for those variables, to evaluate sensitivity to key parameters and assumptions.
4) Develop, evaluate, and exercise an optimization model with the intent of modeling a package of alternative farming operations and comparing results on the basis of operational net returns. The Model must be functional but understandable to the anticipated farmer user.
5) Exercise the optimization model to ascertain outcomes and potentially extrapolate outcomes toward some generalizations that may apply to South Platte farming operations as well as other farming circumstances under prior appropriation water law.
6) Consider what overall future operations might look like if a ditch company or farmer cooperative became the managing entity responsible for operating a plan and reporting to the State Engineer and farm management.

1.9 A Comment on the Package of Technologies Presented.

It is noted and acknowledged that many of the technologies discussed in this dissertation are not new by themselves. Some technologies, in fact, are decades old – for example, the calculation of evapotranspiration for a crop based on climatic data. So, a legitimate question is; how is this approach different, what has changed, or what is really new here? The answer to this question is multi-faceted, but can be clarified by the following points:

1) Farming economics has changed in recent years with evolving price subsidies, consumer-driven initiatives such as organic farming and "buy local" efforts, international market influences, and ethanol production.

2) Supervisory Control and Data Acquisition (SCADA) systems and the associated instrumentation have come down in cost and improved in technical capability over the last decade.

3) Wireless communication options have improved and come down in cost dramatically.

4) Optimization application programs are readily available that bring increased utility and sophisticated techniques to problem solving, such as the complex estimation of consumptive use under irrigation regimes.

And most notably,

5) There are unprecedented pressures on senior water right holders (i.e. most often farmers) to sell their water to a municipal or environmental interest.

Further, the packaged technologies as described in this dissertation can best be framed and viewed in the context of total water management or "TWM." As regional water issues come to the forefront for water planners and the rate paying public, a balance between agriculture, urban, and environmental uses needs to be achieved. TWM will be described further in Chapter 2.

CHAPTER 2
LITERATURE REVIEW

2.1 Definition of Terms and Methodology

The term deficit irrigation (DI), as defined by Marshall English at Oregon State University, is “irrigation that allows stress in a significant fraction of a field at some times during the season” (English and Robinson 2010). (Geerts and Raes 2009) defined DI as “deliberately tolerating drought stress for maximizing the productivity of water.” Freddie Lamm at Kansas State University notes that he defines deficit irrigation as “an irrigation level under the expectation of reduced crop yield with economics justifying the deficit” (Lamm 2010). The term limited irrigation is also widely used but ambiguous (Howell and Tolk 2010). The terms limited irrigation and deficit irrigation are often used interchangeably. It was noted at a recent invited workshop on this topic that there is ambiguity in the terms but it was suggested that “deficit irrigation” is preferred.

As used here, the term “deficit irrigation” or “DI” will refer to purposefully shorting a crop of water, thereby reducing the evapotranspiration rate and saving CU, but with the recognition that crop yield will suffer. The term “limited irrigation” will refer to a reduction of water applications in a farming-based water-budgeted circumstance through a combination of one or more practices, one of which may in fact be deficit irrigation.

Considering deficit irrigation schemes, and aside from understanding the crop water production functions per se, it is interesting to note that there is a discussion occurring within the research community as to how to best implement deficit irrigations and practically maintain historic irrigation return flows. This discussion is driven by knowledge of the crop water production function but also in consideration of the practical and affordable implementation of recharge structures which are often necessary to meet return flow obligations in the correct volume, timing, and place on the river (Altenhofen 2010). If deficit irrigation is accomplished with each irrigation event being systematically shorted, then there is less likelihood of deep percolation below the crop's root zone and new recharge structures will likely be necessary to meet historic return flow obligations. This approach has recently come to be called "shorted application deficit irrigation" or "SADI."

If historical irrigations are made with the full irrigation type of event in mind, and more importantly, if those irrigations were accomplished with surface or flood irrigation, then it may be desirable to continue with the historical irrigation application rate for a single irrigation event. In order to deficit irrigated a crop, this implies fewer irrigation events over the season. This would potentially eliminate the need for recharge structures or diminish the size of or the necessity for new recharge structures. This approach has recently come to be called "low frequency deficit irrigation" or "LFDI."

Note that the effective crop water application could be identical in either the LFDI or the SADI cases, but the delivery approach for return flow waters to meet return flow obligations would differ. The following phrases and abbreviations related to the approach to deficit irrigation will be used:

- Deficit irrigation with each irrigation event shorted and termed shorted application deficit irrigation (SADI).
- Deficit irrigation with fewer irrigation events during the season and termed low frequency deficit irrigation (LFDI).

Tom Trout with the USDA-ARS is currently engaged in a three-year research project east of Greeley, Colorado to evaluate these two DI schemes to compare any difference in crop production functions and differences in return flow patterns (Trout 2010). Data collected during the 2010 first season are currently being reduced and evaluated following crop harvest in November 2010.

One full book on deficit irrigation (Kirda et al. 1999) framed the topic of deficit irrigation beyond a simple one-sentence definition as follows:

> “Through the use of deficit irrigation, crops are purposely irrigated less during the plant growth stages that are relatively insensitive to water stress as regards the quality and quantity of the harvestable yield. Identifying growth stages of particular cultivars under local conditions of climate and soil fertility allows irrigation scheduling for

both maximum crop yield and most efficient use of scarce water resources."

2.2 Limited Irrigation and Deficit Irrigation Literature

The history of basic research in this area is long, varied, and dates back to the 1970s. Early work was primarily intended to show the basic potential for water conservation and achieving a high water use efficiency (WUE) (Hoffman et al. 1990) . The term WUE is frequently used in the literature but (Howell and Lamm 2007) make a good argument for their preferred term "water productivity" in lieu of "water use efficiency" because the word "efficiency" can be confusing with respect to other efficiency terms in irrigation

The more recent work in DI is driven by drought response demands, a desire to predict climate change impacts on crop production, and the possibility of revamping individual farming operations with the intent of maximizing profit as opposed to maximizing crop yield.

The current definitive and in-progress research in the western U.S. is being conducted by Derrel Martin and Ray Supalla at the University of Nebraska, Norm Klocke at Kansas State University, Tom Trout with the USDA-ARS Water Management Unit in Fort Collins, Colorado, Marshall English at Oregon State University, and Neil Hansen with Colorado State University. Several of these research efforts have resulted in Excel-based optimization routines including the Water Optimizer program developed at the University of Nebraska, the Water

Allocator program developed at Kansas State University, and the Agricultural Water Lease Evaluation Tool (AgLET) developed under the auspices of a CWCB-funded grant to Colorado Corn Growers in 2009 and 2010. These optimization programs are described and contrasted further in a subsequent section.

(Geerts and Raes 2009) completed a thorough literature search, in depth and covering a extended time period, and reported on the research, the crops, and crop production functions from journals and publications around the world. An important synopsis from (Geerts and Raes 2009) is that "in areas where water is the limiting factor for crop production, maximizing water use efficiency by DI is often economically more profitable for the farmer than maximizing yield." This quote has key relevance to the topic of this dissertation.

(Howell 2001) refers to water use efficiency (WUE) and nicely defines it from the agronomic as well as engineering perspectives. Interestingly, he notes that in some cases increasing irrigation efficiencies may not achieve "new water" for allocation unless the CU part of the diverted water is actually reduced.

(Lamm et al. 1994) reported on a method and strategy of conserving water which is closely related to deficit irrigation strategies. This method, known as planned soil water depletion, is to "mine" the plant-available soil water gradually during the irrigation season, in anticipation of recharge from precipitation during the winter. With three treatments, WUE was found to be similar whether planned soil water depletion was used or not, and it was concluded that, from a water conservation standpoint, irrigation under a planned soil water depletion strategy was not justified. Yields were found to be linearly related to irrigation and water use.

(Trout et al. 2010) notes that CU can be reduced through deficit irrigation and the reduced or saved portion of the CU can be transferred to other users if it can be quantified. Reference is made to the economics involved, namely that the marginal productivity of the water applied tends to be low when water applications are reduced from full irrigation. He attributes this to increased efficiency of irrigation water applications and, interestingly, a presumed physiological response in plants that increases productivity per unit of water consumed when water is deficient. (Trout et al. 2010) suggests that improved irrigation efficiency is not likely to produce transferrable water because this results primarily in reduced return flow rather than a reduction in CU per se. He says:

> "Under Colorado water law, return flows generally must be maintained when water is transferred. If significant transferable water is to be produced by deficit irrigation, it must result from reduced CU, and result in improved efficiency of the crop to convert CU to yield. Thus, the goal of the "maximize crop per drop" slogan must, in reality, be to maximize crop per consumptively used drop."(Trout et al. 2010)

In the research being conducted by Tom Trout and others at the USDA-ARS research farm east of Greeley, Colorado, plant physiology is understood to be a factor in successful deficit irrigation and the irrigations are timed toward allowing stress during early vegetative and late maturity stages but extra water (less deficit) is applied to reduce stress during reproductive stages. The research is currently in the third year. A key interim analysis of data indicates the following important note as related to this dissertation topic:

> "These results imply that nearly all of the increase in the marginal value of applied water with deficit irrigation results from more effective use of precipitation and increased use of stored soil water, or conversely, the lower marginal value of water near full irrigation is due to inefficient use of rainfall and irrigation water. The marginal value of applied water near full irrigation would be even smaller with less efficient irrigation systems, since more of the applied water would be lost to runoff and deep percolation. These results also imply that, based on consumptive use, there would be no yield benefit to deficit irrigation compared to fully irrigating only a portion of the land. In fact, fully irrigating less land would likely provide the highest economic returns due to lower production costs.
> These preliminary results show the importance of developing water production functions based on the correct unit of water. If water value is based on cost of the water supply (e.g., pumping costs from a well), then productivity based on applied water is important. However, for the purpose of transferring consumptive use savings, the productivity must be based on water consumed. The value of limited irrigation based on CU savings will likely be less, and if the crop is efficient at converting increased CU to yield, there may be no economic benefit to limited irrigation". (Trout et al. 2010)

(Hanson et al. 2010) have recently reported on two of the three years of research conducted at Iliff, Colorado on cropping systems. A water balance approach was used to determine evapotranspiration and drainage, crop yield, and water use efficiency for rotational cropping, limited irrigation (aka "deficit irrigation") and partial season irrigation. In particular, this work found that "rotational cropping systems that alternate irrigated crops with fallow or dryland crops were effective at reducing ET by 30 to 40 percent as compared to continuous corn. This approach spans multiple cropping years so it cannot be evaluated or “optimized” in the context of a single crop year. However, multiple runs of an optimization program could accomplish a suitable result.

(Martin et al. 1984) developed a simulation model to estimate the effect of deficit irrigation on crop yields. The model was developed to provide “relative yield estimates” for combinations of irrigation systems, crop growth, and irrigation management parameters. Crop production functions that use physically defined parameters were developed to relate crop yields to gross irrigation requirements. A key aspect of this work is that the model, the model inputs, and the crop production functions are general. They depend on readily available information and physical parameters. The underpinning use of the model is to evaluate irrigation management alternatives. This model was developed and reported before wide spread use of desktop computers so no easily exercised computer program is known to exist for this model but it appears to be definitive, understandable, and reasonable with required inputs and key assumptions.

A general conclusion can be made about deficit and limited irrigation strategies based on reviewing the body of literature that spans 40 years and reports on research conducted predominately in North American, China, Europe, and the Middle East. The practice of deficit irrigation can generally produce high crop yields with high crop water use efficiencies (WUE) provided proper choices of irrigation timing and amounts can be made. Deficit irrigation also has the advantage of increasing fertilizer use efficiency as well as decreasing the potential for leaching losses of fertilizers and plant nutrients. For the same amount of irrigation application, it can be shown that there are different irrigation management alternatives for creating water stress during the particular plant growth stage or for purposeful partitioning water stress (and water applications) through the season (Kirda et al. 1999).

2.3 Crop Water Production Functions

(Geerts and Raes 2009) defined and typified the general shape of a crop production function with definition given to differing portions of the curve. Their figure is reproduced here as Figure 8. Curve sections (a), (b), (c), (d), and (e) in Figure 8 vary in width for different crops. Relative yield is defined as the ratio between actual and potential yield for the agronomic conditions. Relative evapotranspiration is defined by (Geerts and Raes 2009) as the ratio between the seasonal amount of water that is evapotranspired and the seasonal crop water requirement.

(Geerts and Raes 2009) note that research from around the world confirms that “DI is successful in increasing water productivity for various crops without causing severe yield reductions.” The prevalence of research papers that were reviewed was conducted on wheat, maize, corn, potato, cotton, soybean, onion, alfalfa, quinoa, and sugarbeets. The reviewed papers can be broken into two categories – papers on a specific crop or crops and papers of a more general nature on the strategies of deficit irrigation.

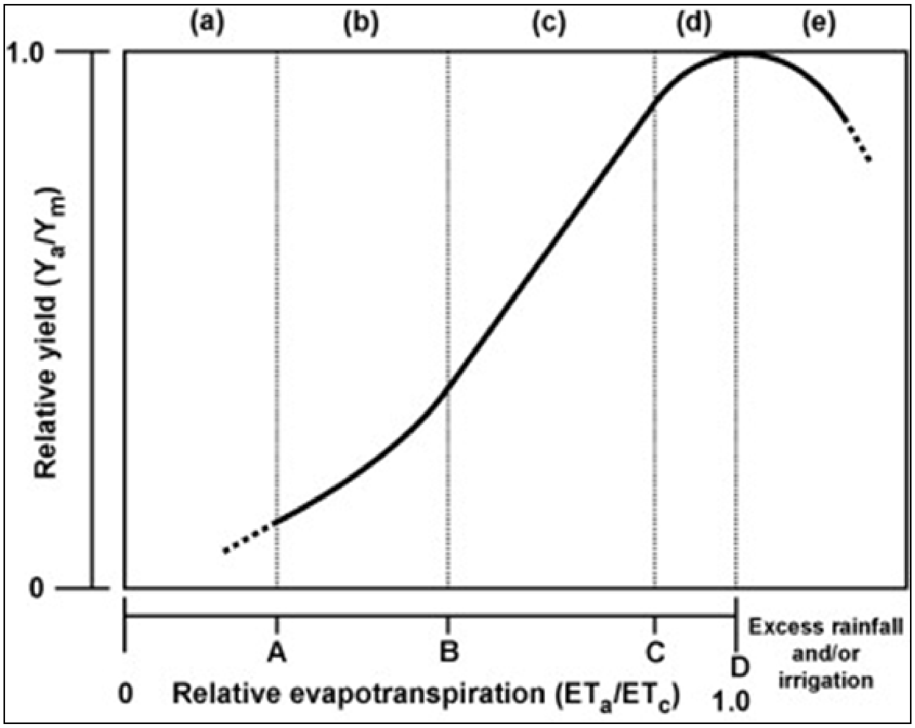

Figure 8. The general shape and characteristics of the crop water production function (Geerts and Raes 2009).

Referring to Figure 8, note that sections (d) and (e) are relatively flat compared to sections (b) and (c) which show the greatest slope and therefore the greatest benefit from an incremental amount of evapotranspiration. This is important in the context of deficit irrigation. If a deficit irrigation practice is to be considered and implemented, the "more crop per drop" aspect of the strategy is likely to be accomplished within the (b) and (c) sections of the crop water production function.

2.4 Crop or Water Optimization Software Programs

Water Optimizer is a software tool developed at the University of Nebraska, based in Excel and using the Solver functionality of Excel 2007, for analyzing alternative water management strategies when the available water supply is limited. Farmers are encouraged to use the program to determine the "profit maximizing crops to produce and the optimum amount of water to apply to each crop" (Martin et al. 2008). Figure 9 from the Water Optimizer manual shows the general relationship between yield and evapotranspiration on which the program is based.

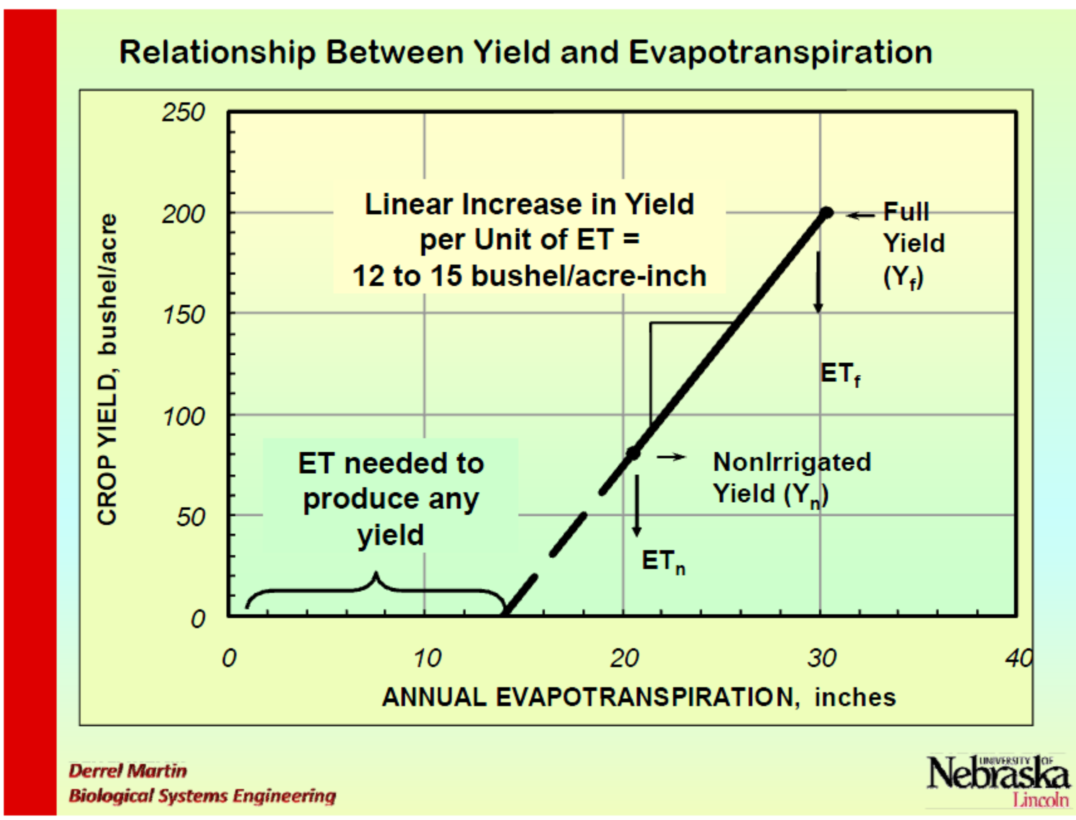

Figure 9. Explanatory background material on the Water Optimizer software (Martin et al. 2008).

Program inputs are:

- A specific Nebraska county.
- Soil type.
- Irrigation (gravity or pivot).
- Water cost.
- Crop (corn, soybeans, wheat, grain, sorghum, alfalfa, edible beans, and sunflowers).

Use of the program in the Republican and Central Platte basins of Nebraska shows that, in most cases, the optimum strategy for limited water situations is to continue to irrigate the same acreage and the same crops at less than full irrigation (i.e. deficit irrigation) when the water supply can be 80% of the full requirement. If water supply is less than the 80% of full irrigation requirement, it may be advantageous to plant some acres to lower water requirement crops or reduce irrigated acres.

One regional aspect and limitation of Water Optimizer to be aware of is that it is geared toward Nebraska counties and toward pumped water situations as found with center pivot sprinkler irrigation in the region. Another limitation of Water Optimizer is that it is limited to one field whereas there may be many fields on a single farm. An advantage of Water Optimizer is that it runs with the third-party add-in that is delivered with Excel 2007 and requires no further user expense to upgrade the basic add-in. The program can be found in the public domain at http://www.agecon.unl.edu/wateroptimizer/download.html.

The Agricultural Water Lease Evaluation Tool or "AgLET" has just recently been shown and vetted with Colorado State University Extension Personal. The program is based in Excel and was developed by a consulting team led by Colorado Corn Growers. Others participating in the team include Ducks Unlimited, Brown and Caldwell, and Harvey Economics. Funding was provided by the Colorado Water Conservation Board. This Excel tool does not use the Frontline Systems' Solver but does have a tabular and automated sensitivity analysis built in that allows the user an overview of output parameters based on a plus / minus percent around a variable. The alternatives of deficit irrigation or fallowing as the basis of an interruptible water supply contract can be evaluated.

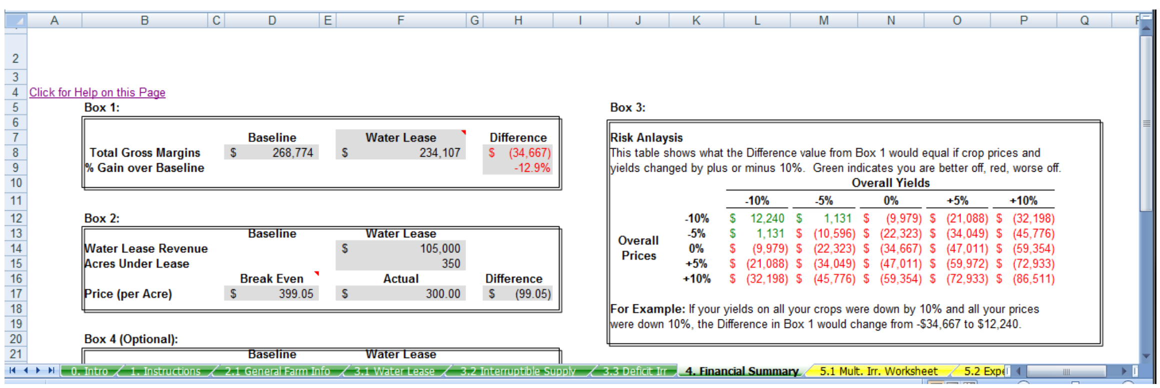

Figure 10. AgLET output page (screen capture) comparing gross margins and providing some limited sensitivity analysis (Pritchett and Cabot 2011).

CROPLAN is an integrated expert system for crop planning as conceptualized and developed in 1992 by Amnon Nevo (Nevo 1992). This research and program (CROPLAN) focuses on the total crop planning exercise as opposed to more limited-scope mathematical optimization per se. The work recognizes factors spanning multiple disciplines, specifically economics, engineering, and sociology.

Recognizing that “a naïve formulation of a linear programming model may exceed hardware limitations of the computer”, the inputs into the model come from a knowledge base formed by “cropping rules” and miscellaneous “considerations rules.” Considerations rules are crop independent and bring in underlying planning elements, often subjective, to the program. A separate rule is formulated from user input and other subjective input factors. The work notes repeatedly that computer and software limits of the time must be considered and the approach to formulating the model is very practical and functional in this regard. The linear programming code is brought in as a module to the program and is based on (Press 1986). The optimization objective function as stated is “to determine the expected profit from a unit area of each crop.” But, as also noted “to simplify the task of profit estimation, it has been disaggregated into small components; instead of estimating profit of a crop directly, the system estimates the inputs and outputs involved in the production of that crop.” This is net return as defined in Chapter 3. This dissertation was found to be quite fascinating in the context of the work described and as related to the dramatic effective increase in computer speed and capability over the past 20 years.

2.5 Leasing Water as a Water Transfer Method

(Pritchett et al. 2008) studied water leasing as an alternative to outright water acquisition by municipalities. The focus was on the South Platte River Basin. Favorable conditions for establishment of water lease markets were noted as follows:

1) A critical mass of willing leasers and water right holders.

2) Potential gains from leasing exceed transaction costs.

3) Leasing contracts can be written, monitored, and enforced effectively.

The primary question that was addressed, via a critically reviewed professional questionnaire, is “are farmers willing to sign water leases if suitably compensated and what remuneration is needed?” Results from questionnaire analysis are briefly summarized here relative to the responses that are most pertinent to this dissertation:

1) Respondents believe that leases can be a source of revenue for farmers and that rural communities are better off with leasing as compared to “buy and dry.”

2) A majority of the respondents indicate they would be willing to sign a lease if suitably compensated.

3) A vast majority of respondents indicate that the minimum acceptable annual lease price is in the range of $225 per acre to $575 per acre.

Considering the response (#3) to the minimum acceptable annual lease price, note that the units are expressed as dollars per acre ($/acre). The other units that are often attached to a water lease are dollars per consumptive use acre foot ($/AF). The conversion from one unit to the other is not trivial or simple because different surface water rights have highly differing amounts of consumptive use water associated with the irrigated areas. This is all related to the historical CU and is quantified through an engineering study as described in Chapter 1. Under the New Cache Irrigating Canal Co. (aka Greeley #2), the engineering report prepared by HRS Water Consultants indicates that historic CU per acre is 0.83 AF / AC. So, at least in this case, the responder-acceptable $/AC can be translated to $271 to $693 per AF of CU water (HRS Water Consultants 2010).

Appendix 2 contains an example water lease agreement between High Line Canal and the City of Aurora. This agreement was used to affect a lease between these two entities in 2003, a drought year, using Colorado Statute 37-92-308.

Two existing Colorado Statutes might be used for leasing agreements between a “water lender” and a “water borrower.” Each of these statutes can be found in Appendix 3. The terms “water lender” and “water borrower” are taken from Statute 37-92-309. It is assumed that these terms avoided terms that might imply a water sale as opposed to a water lease.

2.6 Aspects of Total Water Management

Total water management is a concept that emanated initially from American Water Works Association’s task force work in 1994 (Grigg 2008). Total water management is about:

- Principles and practices.
- Stewardship.
- Sustainability in water resources.
- Water management.
- Water conservation.
- Cooperative spirit among water users.

- Assessment and reporting.

The package of technology, call it the System, described in this dissertation exemplifies strong elements of total water management because it embodies the qualities noted above

CHAPTER 3
CONSIDERATION OF THE OPTIMIZATION MODEL INPUTS AND REQUIREMENTS

3.1 Farming Practices

This chapter explains the basis for, and the underpinning considerations of, the Model. At a higher philosophical level, this optimization Model assumes there are demands for, and a higher economic value for, a proportion of the farmer's CU water. Analysis of various practices available to the farmer will assist in setting the stage for future farming operations that may have a favorable overall effect on the farmer's annual income.

In the South Platte River Basin, the predominant irrigated crops are corn, wheat, dry beans, grass hay, alfalfa hay, and truck crops (vegetables) (Dunn 2010). Within the Model, consideration can be given to the practices, or more likely the combinations of suitable practices, that lend themselves to an annual CU water budget optimization scheme.

In any given year, practices may include:

- Deficit irrigation (DI).
- Introduction of new crops, including perennial crops.
- Permanent fallowing or rotational fallowing.

- Introduction of dryland crops.
- Continued full irrigation (FI) of selected crops.
- Crop rotations (implies multiple years).
- Combinations of the above.

In subsequent years, a farmer might choose different combinations of these practices. Farmers have indicated in informal, personal interviews that they will consider alternative practices if it makes economic sense for them and their farming operations (Magnuson and Trowbridge 2010). Feedback from interviews was quite positive in regard to consideration of deficit irrigation, especially if it can be considered in combination with other practices such as permanent or rotational fallowing. Some farmers were not familiar with the concept of deficit irrigation but thought it might work. Some were skeptical that a deficit irrigation program could be accepted by the Colorado Water Court, and decreed as such, because of the implied additional burden of proof as compared to permanent fallowing (Dunn 2010). This last point is well taken in that when fallowing is implemented, the ground is reseeded, and then the monitoring to support the claim of fallowing is easy to conduct. Rotational fallowing or deficit irrigation, respectively, are more difficult and time consuming to monitor and report on to the State. Difficulties occur because of the need to instrument, monitor, and report where water is delivered and where return flows can be documented. DI operational reporting will require a rather high level of instrumentation to include water delivery measurement, continuous ET measurement, possibly deep percolation estimates or measurement, and surface return flow measurement. Not only must these measurements be suitably accurate, but they must be reported to the State in a timely fashion to support the water right change decree (Belt; 2010).

Crop rotations or new crops should be considered because of new or potential markets and because of crop diversification and risk management within the bigger package of considered practices. Even new perennial crops may have potential if the farmer wants to diversify and grow crops that have benefits of high value and lowered production costs. An example might be wholesale nursery tree production under automated drip irrigation, which could represent a completely new strategy and a paradigm shift for a farmer. Plus new opportunities may be related. Drip irrigation implementation can potentially be cost shared under the NRCS Environmental Quality Improvement Program (EQIP) and the changed practices can include irrigation applications to only the field area under the tree canopy – something of a fallowing of all unplanted areas that are not under the tree canopy. This understandable and implementable approach to ET monitoring and irrigation scheduling with drip irrigated trees is suggested early on by (Keller and Karmeli 1975).

Permanent or rotational fallowing, as mentioned earlier, is an easy practice to implement, monitor, and report. With permanent fallowing, previously irrigated fields are taken out of production and reseeded in native or acceptable nonnative grasses. Irrigation for establishment of the grass may be desirable or even mandated by a change decree, and if so, the field is not considered to be fallowed until it is no longer irrigated. Rotational fallowing, by contrast, may be seeded in a suitable dryland cover crop until the land is rotated back into production.

Dryland farming is easy to implement and monitor as well. Previously irrigated fields are plowed out and planted in dryland wheat, or corn, or another suitable crop, and farmed each year in consideration of annual precipitation. Yields will of course be variable and sensitive to actual precipitation levels in any given year.

Within the package of the above-mentioned “considered practices” and depending on what percentage of the CU budget is up for scrutiny in a continued farming operation, full irrigation can be and should be considered. Additionally, this choice may be driven by a range of subjective farmer-driven variables, including familiarity with a crop, remaining useful life in farm equipment required for that crop, level of irrigation automation available, and other personal preference considerations.

Depending on many factors, a farmer may wish to consider any and all of these practices -- taken together collectively -- into a modeled scenario. The output of a single model run would be to compare annual CU water requirements and a forecast of net return. Multiple scenarios might be compared one to the other or taken into consideration for a multi-year analysis of practices on the basis of net returns.

3.2 New or Upgraded Irrigation Systems

It is appropriate to consider irrigation system upgrades or expansion within the context of evaluating changed practices. Some irrigation systems lend themselves nicely to continued full irrigation, but potentially in a more efficient manner. Some irrigation systems can be adapted well to return flow maintenance, as per the example of continued furrow irrigation of corn, because historic return flow patterns can be maintained and easily reported (i.e. no change in past practices).

Much of the irrigation in the South Platte Basin is accomplished with surface methods. This is especially true of corn. Surface irrigation will continue for the foreseeable near future to be the dominant irrigation method. It does not require energy, it is low cost and adaptable to changing field layouts, and it is reasonably efficient if viewed in the context of the inherent return flows. Surface and subsurface return flows are in one sense wasted to the farm from which they flow, but those return flows are a downstream user’s historic water source and possibly the strength of their water right.

Pressurized irrigation, to include drip and sprinkler irrigation systems, offers significant increases in irrigation application efficiency as compared to surface irrigation. That said, and with the technology package described in this dissertation, there is no compelling justification for a farmer to move to pressurized irrigation to fulfill the requirements of a water leasing program. In fact, once a change decree is in place, the conversion and upgrade to more efficient irrigation systems may entail new return flow delivery and recharge structures just to maintain historic return flows without injury to downstream users. There is a definite irony in this -- the issues are not obvious to the casual observer.

There is a reasonably good potential for a farmer participating in a long term water lease program to utilize the new income stream for irrigation system improvements. These improvements may fit very well with some changed practices -- drip irrigation, for example, would likely be important with a new, fully irrigated perennial crop. Likewise, irrigation system automation, irrigation scheduling tied to a nearby weather station, soil moisture monitoring, and other modern irrigation technologies could be complementary to a leasing program, although perhaps not necessarily mandated by a leasing program.

The Natural Resources Conservation Service cost shares certain irrigation system improvements with farmers. The program, known as the Environmental Quality Improvement Program or EQIP, is administered state-by-state. Farmers in a future leasing program may wish to avail themselves of EQIP funding to complement overall improvements to their farming operations. The benefits of

EQIP complement nicely with much of the implementation hardware requirements described in Chapter 5.

3.3 Evaluation of Optimization Application Programs

Several companies offer robust and adaptable optimization application software with optimization routines built in. Algorithms built into application software have brought optimization to the forefront as a more likely problem solving tool for use in common business problems. One of the most popular and readily available examples comes bundled into Microsoft Excel as a third-party add-in created by Frontline Systems (Walkenbach 2006), (Larsen 2009), and (Gottfried 2009). Information on the various Solver program options can be found at http://www.solver.com/. These optimization options and linear programming add-in are commonly referred to simply as "Solver." As a Solver model was developed and exercised for the purposes of this dissertation and Model development, it became clear there were limitations, especially in regard to the maximum allowable number of constraints and variables. As noted earlier in Chapter 2, one limitation of the Water Optimizer program is that it is for one field only and not for multiple fields, the latter of which generally characterizes a modern farming operation.

Optimization algorithms and problem solving using linear programming techniques is a powerful approach to solving complex problems. The increased use of practical applications programs such as the Solver add-in to Excel, is directly related to the increased use of personal computers and the increased speed of those computers.

After evaluation and study of application programs, the Frontline Systems Premium Solver Platform was found to be suitable to a typical full farm operation. More specifically, the Premium Solver Platform model was developed to support a combination of 20 fields, 18 full irrigation crops, and seven limited irrigation crops per field. This maximum combination of variables may not be the limitation of the Premium Solver Platform but, at this time, this combination of variables is running successfully in the Model and an optimal solution can be found.

Additionally, the Model described here has recently been imported into the Frontline Systems Software Development Kit (SDK) so that the utility of the program can be delivered and run on a web interface and server. Screen captures presented in Chapter 4 are from the internet delivered version of the optimization. To the farmer user (perhaps as well to the reader of this dissertation), these screens are more easily viewed and understood than in a typical Excel worksheet screen.

3.4 Decision Support and the Optimization Model Operation

The farmer user can choose the best option from some set of available alternatives. Multiple runs of the Model can result in a user-defined sensitivity analysis with output reports from multiple runs of the Model.

The spreadsheet Solver-based optimization Model can be simply described as follows:

- Treated as an integer programming problem using a standard linear programming simplex engine in the Premium Solver Platform.
- Water production functions curves are set up as step functions (points) with 21 levels, in order to avoid a non-linear problem and the added run time and propensity for non-convergence by the Solver.

The preliminary concept of the look and feel of an Excel-based optimization model was developed as shown in Figure 11. This layout was thought to provide a simple interface and understandable to most potential users. It is most desirous that a decision support tool like this be intuitive and easy to understand, assuming one understands already the basic data inputs.

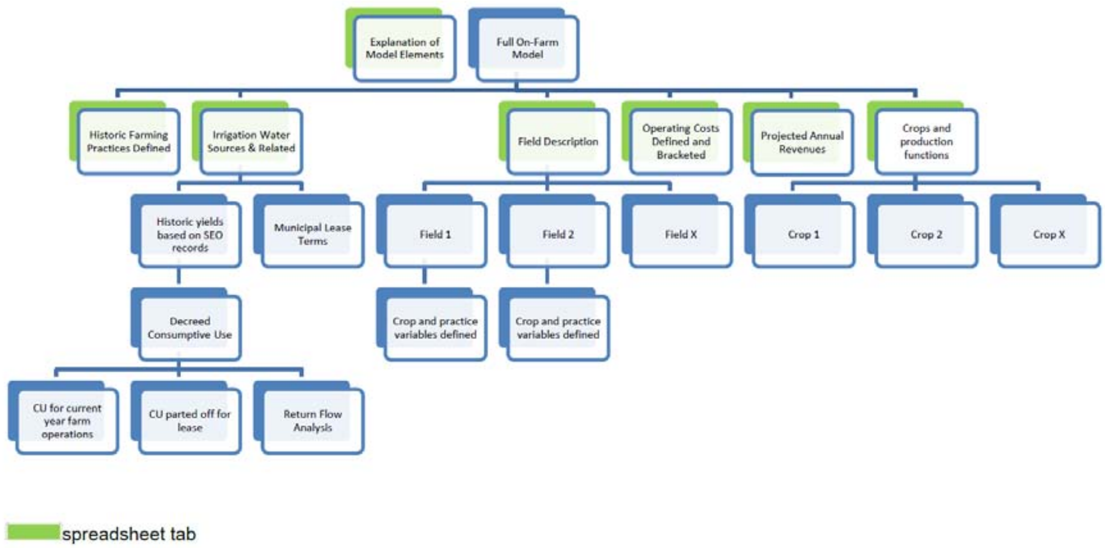

Figure 11. Initial Excel spreadsheet layout concept for the Model.

As to the optimization portion of the spreadsheet, the flow of the user's experience was conceptualized as shown in Figure 12. A user can enter or change data on fields, crops, irrigation, and other practices, and then run the optimization model. If that particular optimization run is of interest, then the results can be stored. When a particular optimization is finalized and up for consideration in the pending season, that data can be uploaded into a larger data base for inclusion into larger operations plans that can be adopted by the ditch company or cooperative operating entity.

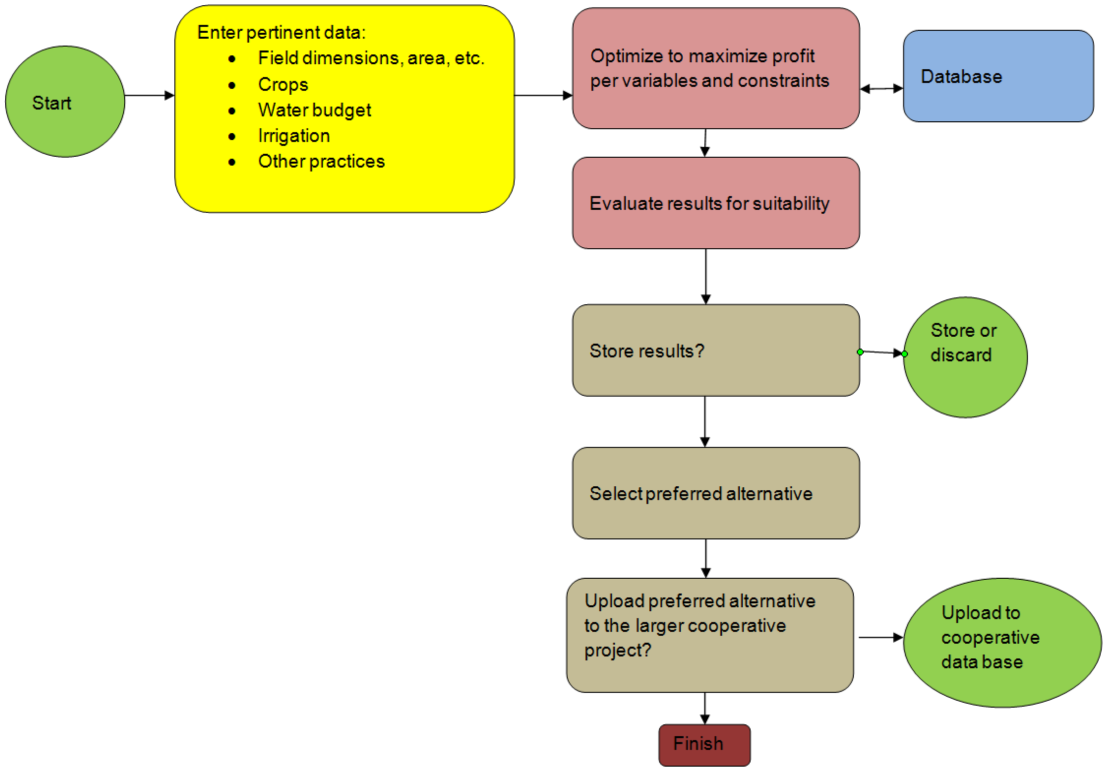

Figure 12. A concept of the Model flow and the anticipated user experience and uploading potential to a ditch company or cooperative entity.

The optimization Model is broadly defined in consideration of the elements that characterize all mathematical optimization models, namely the parameters, decision variables, constraints, and the primary objective function. The objective function is defined for the purposes of this Model to be the maximized projected net returns to the farming operation.

Net return is the income from an investment after deducting all expenses from the gross income generated by the investment (businessdictionary.com 2010). Net returns in a farming operation is defined to be farm revenues minus the fixed operating costs. Net return has also been defined as the return to land and management. On the other hand, farm net returns, by definition, does not include land costs, interest, taxes, and other costs that are fixed regardless of irrigation decisions (Martin 2010).

$$net\ returns\ = revenue - fixed\ operating\ costs$$

This can also be considered in the following way after (Martin 2010):

net returns =

net crop price x crop yield

minus irrigated crop production costs

minus cost of water x depth of irrigation applied

This approach to using net returns as the primary means of comparing one model run to another is affected by some important farmer client issues as well. These include:

1) The availability of detailed farm financial data.

2) Potential reticence of the farmer to disclose detailed personal financial data, even if readily available.

3) Time considerations – the desirability of farmers to quickly enter input data to see some preliminary results, combined with their possible lack of willingness to spend hours on data entry setup (Magnuson and Trowbridge 2010) and (Sponsler 2010).

The decision variables are assumptions and values for all inputs costs, crop yields, and crop prices. The default decision variables embedded in the Model are found in Appendix

1. These default values were obtained largely from the National Agricultural Statistics Service database (http://www.nass.usda.gov/) but with minor inputs of data from other peripheral sources when the NASS database did not have the needed data (Dunn 2010). It should be noted that the defaults are simply place holders that allow for quick data input. However, the Model's input data can easily be changed for farm-specific circumstances, or experience, or for that matter, contractual pricing that may be obligatory.

Default data should also be changed when farm current market influences need to be recognized. Examples of significant influences are increased market price for corn as influenced by ethanol plant demands or increased price for wheat as influenced by Russian exports of wheat dropping off.

There are four categories of crops in the Model. Crop categories and the underlying assumptions with those crops are:

1. Full Irrigation (Enough irrigation to maximize yield or profit)
   Yield = f(crop, soil type) = constant
   Water for fully irrigated yield is f(crop, soil type) = constant
   Fixed production costs > 0
   Variable production costs > 0
   Price > 0

2. Dryland (No irrigation)
   Yield = f(crop, soil type)

Water = 0
Fixed production costs > 0
Variable production costs > 0
Price > 0

3. Fallow (No crop, but weeds must be controlled after an establishment period so there are fixed production costs)
   Yield = 0
   Water = 0
   Fixed production costs > 0
   Variable production costs = 0
   Price = 0

4. Deficit irrigation (The crop is irrigated with 10 to 90% of the amount of irrigation to achieve maximum yield in 10% bracketed increments)
   Yield = f(crop, soil type, irrigation method, irrigation): a nonlinear function
   Fixed production costs > 0
   Variable production costs > 0
   Price > 0

The designated 27 crops that are currently available within the Model are:

Fallow
Fully Irrigated Corn - grain
Fully Irrigated Corn - silage
Fully Irrigated Winter Wheat
Fully Irrigated Barley
Fully Irrigated Alfalfa
Fully Irrigated Pinto Beans
Fully Irrigated Sugarbeets
Fully Irrigated Onions
Fully Irrigated Cabbage
Fully Irrigated Carrots
Deficit Irrigated Corn - grain
Deficit Irrigated Corn - silage
Deficit Irrigated Winter Wheat
Deficit Irrigated Barley
Deficit Irrigated Alfalfa
Deficit Irrigated Pinto Beans
Deficit Irrigated Sugarbeets
Dryland Corn
Dryland Winter Wheat
Dryland Barley

Dryland Alfalfa
Dryland Canola
Dryland Sorghum
Dryland Millet
Dryland Sunflower

Note that some crops are not allowed (not listed) as “deficit irrigated” or “dryland” under the presumption that these crops would not be grown as a practical matter, in the South Platte Basin, under deficit irrigated or dryland conditions.

Farmers will most certainly have subjective preferences about the crops to be grown:

- For some crops, the farmer may have a minimum or maximum amount of desirable acres. For example, corn may be needed to feed cattle.
- The farmer will not grow a crop if money will be lost in growing it. Therefore, net return $\geq$ 0 for a field, with the exception of fallowing.
- The farmer has preferences for the crop(s) he or she is willing to grow and this can be input on a field by field basis.
- Only one crop can be grown on any one field.

The constraints in the Model are essentially farmer impositions on the model. These include decisions and/or assumptions that are associated with the overall farm operation or the assumptions for the pending year under evaluation. Examples of constraints are:

1) The minimum and maximum acreage of the various crops to be grown.

2) Willingness to employ certain practices (deficit irrigation, fallowing, etc).

Table 2 summarizes the primary elements of the optimization model created for this problem and provides examples of defining equations.

Figure 13 graphically shows the inputs to the model and the optimized (modeled) net return. A successful run of the optimization model indicates the projected net return associated with the crops to be grown along with crop yields, the practices to be adopted, and the anticipated unit prices. This modeled net return can then be contrasted with the historic net return from the farming operation.

Table 2. Linear Optimization Model Elements Defined.

	Element Definition	Equation Examples Specific to this Model	Notes or Clarification
Objective Function	The quantity that is to be minimized or maximized using optimization techniques and algorithms.	Objective function = maximized net return, NR Net return, NR = revenue – fixed operating costs	Maximized net return is the NR based on the imposed constraints, decision variables, model parameters, and user inputs.
Constraints	Constraints are quantities that constitute physical limits and define the boundaries within which the model attempts to find an optimal solution.	Field 1 Acreage = F_1 Field 2 Acreage = F_2 Total farm acreage = $\sum (F_1 \ldots F_X)$ A user may enter a min and max number of acres for each crop and each fallowed field. NR $\geq$ 0 unless it is fallowed. Available water CU volume $\leq$ W For a deficit irrigated crop, the user defines a min and max percent of full irrigation that can be applied. Crops: Fully irrigated corn = “yes” deficit irrigated wheat = “no” Full irrigation yield = Y_2 Dryland yield = Y_1	Taken collectively, constraints limit the possible crop / field and water combinations and define limits for the whole of the farming operation for the year modeled. Each individually named field has constraints and the farm as a whole has constraints.

Table 2. Linear Optimization Model Elements Defined (continued).

	Element Definition	Equation Examples Specific to this Model	Notes or Clarification
Decision Variables	Quantities that can be varied within the model to optimize the objective function or in making comparisons between differing model runs. Also, variables that the Model sets to maximize net return during an optimization run.	The crop and amount of water for each field	Examples of decision variables are crop selection and cropped acreage needed to achieve $R within the defined constraints. The decision variables represent the crop selected for each field and the amount of water applied to each field.
Model Parameters	Fixed input assumptions that do not change during a model run. Biological and economic assumptions that influence the optimal solution but are set for a single Model run based on user inputs or assumed values.	Crop water production functions and variable crop production costs. Soil type for each field. Irrigation method for each field.	See Appendix A for default values -- operating costs and associated units by crop and full irrigation yield averages.

Note:

1) Crop water production functions are a linear relationship between ET and yield that is adjusted to the efficiency of the irrigation method. The result is a non-linear, hyperbolic relationship between water and crop yield.
2) Parameters of the water production function are the amount of water for a fully irrigated yield depending on crop and soil type.
3) Crop yields with full irrigation or no irrigation are dependent on crop and soil type.

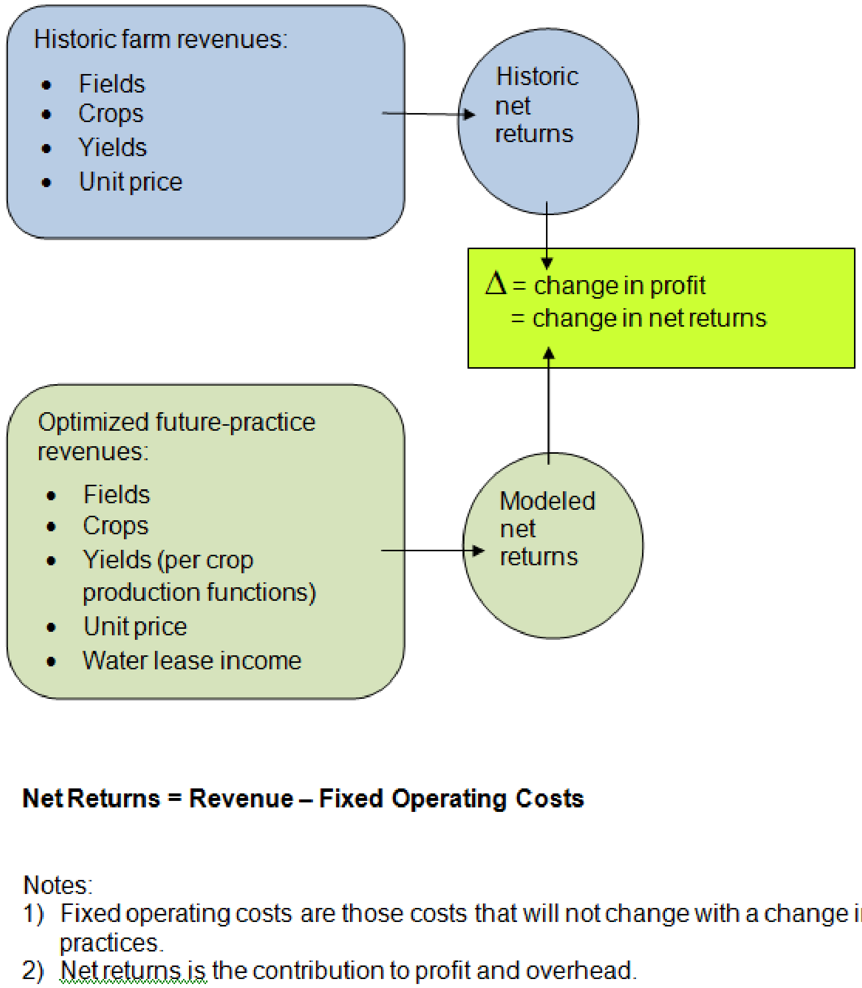

Figure 13. Optimized future practices compared to historic practices on the basis of net returns.

As noted previously, the Model was first developed in Excel using the Solver add-in to Excel. More specifically the Premium Solver Platform was used so as to not significantly limit the number of fields or optimization defining constraints. As the developing Excel spreadsheet became functional and stable, the Model was brought into a web interface so that:

1) The program could be delivered to a farmer-user by downloading it from a server.

2) The user interface could be narrowly and cleanly defined, better than in Excel, to enhance the user experience.

So, the decision variables, parameters, and constraints that embody the optimization model, aka the Model, can currently be operated and exercised as:

1) An Excel spreadsheet using Solver as licensed and delivered with Microsoft Excel 2010 but with limits such that the maximum number of constraints is not exceeded. This spreadsheet model has a maximum of four fields and 7 crops.

2) An Excel spreadsheet using Solver Premium Platform as licensed by Frontline Systems. This spreadsheet model has a maximum of 27 fields, 7 of which can be deficit irrigation fields, and 18 crops.

3) A web interface delivered and a server based Frontline Systems SDK based program with the same limits as 2) above.

Model runs for this dissertation have all been run in the web-based version of the program.

Mathematically, the Model and the optimization equations are expressed by the following series of equations with the associated variables defined in Tables 3, 4, and 5.

$$\boldsymbol{NR_{farm}} = \sum_{f=1}^{nfld} fldsize_f \cdot \left\{ \begin{array}{c} \sum_{ndi=1}^{numNDI} \left\{ \boldsymbol{selNDI_{f,ndi}} \cdot \boldsymbol{NR_{f,ndi}} \right\} + \sum_{di=1}^{numDI} \sum_{s=1}^{numDIWat} \left\{ \boldsymbol{selDI_{f,di}} \cdot \boldsymbol{selDIWat_{f,s}} \cdot \boldsymbol{NR_{f,di,s}} \right\} \\ - \left[1 - \sum_{ndi=1}^{numNDI} \boldsymbol{selNDI_{f,ndi}} - \sum_{di=1}^{numDI} \boldsymbol{selDI_{f,di}} \right] \cdot falcost \end{array} \right\}$$

Net return for the farm is the field size times the net return per acre for the field for non-deficit irrigated crops (first term)), deficit irrigated crop (second term) and fallow (third term).

Net return for the field is net return of the non-deficit irrigated crop ($NR_{f,ndi}$), if grown (**$\mathbf{selNDI_{f,ndi}}$** =1 for some **ndi**),

OR

net return of the deficit irrigation crop ($NR_{f,\ di,s}$) at the selected level of deficit irrigation (**$\mathbf{selDIWat_{f,s}}$** = **1 for some s**), if grown (**$\mathbf{selDI_{f,di}}$** = 1 for some **di**),

OR

the cost of fallow if no crop is grown (**$\mathbf{selNDI_{f,ndi}}$** = 0 for all **ndi** and **$\mathbf{selDI_{f,di}}$** = 0 for all **di**).

Net return for a field **f** and a crop (**ndi** or **di**) is net return minus the fixed costs for the crop minus the variable costs of irrigation minus the fixed costs of irrigation.

$NR_{f,ndi}$ is net return for NDI crop **ndi** in field **f** :

$$NR_{f,ndi} = [p_{ndi} - vc_{ndi}] \cdot yld_{f,ndi} - fc_{ndi} - [nir_{f,ndi}/aeff_f] \cdot vic_f - fic_f$$

In this equation, $nir_{f,ndi}$ is net irrigation requirement for full yield of crop ***ndi*** in field ***f*.** $NR_{f,di,s}$ is net return for DI crop di in field f with deficit irrigation water level s. For deficit irrigated crops, the yield and the variable costs of irrigation depend on the irrigation(s) selected.

$$\boldsymbol{NR_{f,di,s}} = [p_{di} - vc_{di}] \cdot yld_{f,di} \cdot ryld_{f,s} - [nir_{f,di}/aeff_f] \cdot rirr_s \cdot vic_f - fic_f - fc_{di}$$

In this equation, the relationship between yield and irrigation is described as a relationship between the proportion of net irrigation requirement of the crop and proportion of full yield (yield if net irrigation requirement of the crop is fully met). In other words, the crop water production function is defined as *ryld~rirr*. More specifically, the crop water production function is incorporated in the model as ***numDIWat*** paired values of *ryld* and *rirr*.

When all of the mathematical detail described above is combined into one equation***:***

$$\boldsymbol{NR_{farm}} = \sum_{f=1}^{numfld} fldsize_f$$

$$\cdot \left\{ \sum_{ndi=1}^{numNDI} \left\{ \boldsymbol{selNDI_{f,ndi}} \right. \right.$$

$$\left. \cdot \left[[\mathrm{p_{ndi}} - \mathrm{vc_{ndi}}] \cdot \mathrm{yld_{f,ndi}} - \mathrm{fc_{ndi}} - [(\mathrm{nir_{f,ndi}}/\mathrm{aeff_f})] \cdot \mathrm{vic_f} - \mathrm{fic_f} \right] \right\}$$

$$+ \sum_{di=1}^{numDI} \boldsymbol{selDI_{f,di}}$$

$$\cdot \left[\sum_{s=1}^{numDIWat} \left\{ \boldsymbol{selDIWat_{f,s}} \right. \right.$$

$$\left. \left. \cdot \left[[p_{di} - vc_{di}] \cdot yld_{f,di} \cdot ryld_{f,s} - \left[\frac{nir_{f,di}}{aeff_f} \right] \cdot rirr_{f,s} \cdot vic_f \right] \right\} - fic_f - fc_{di} \right]$$

$$\left. - \left[1 - \sum_{ndi=1}^{numNDI} \boldsymbol{selNDI_{f,ndi}} - \sum_{di=1}^{numDI} \boldsymbol{selDI_{f,di}} \right] \cdot falcost \right\}$$

Decision variables are binary: $\boldsymbol{selNDI_{f,ndi}}$; $\boldsymbol{selDI_{f,di}}$; $\boldsymbol{selDIWat_{f,s}}$

The farmer must be willing to grow a crop in a given field:

$$\boldsymbol{selNDI_{f,ndi}} \leq willNDI_{f,ndi} \quad for\ all\ \boldsymbol{ndi, f}$$

$$\boldsymbol{selDI_{f,di}} \leq willDI_{f,di} \quad for\ all\ \boldsymbol{di, f}$$

There is a limit on the amount of water available:

$$\sum_{f=1}^{numfld}\left\{\frac{fsize}{aeff_f}.\left[\sum_{ndi=1}^{numNDI}\left\{\boldsymbol{selNDI_{f,ndi}}\cdot nir_{f,ndi}\right\}\right.\right.$$

$$\left.\left.+\sum_{di=1}^{numDI}\left\{\boldsymbol{selDI_{f,di}}\cdot nir_{f,di}\cdot\sum_{\boldsymbol{s=1}}^{\boldsymbol{numDIwat}}\left\{\boldsymbol{selDIWat_{f,s}}\cdot\boldsymbol{rirr_{f,s}}\right\}\right\}\right]\right\}$$

$$\leq total\ irrigation\ water$$

The Model assumes a maximum of one crop per field:

$$\sum_{ndi=1}^{numNDI}\left\{\boldsymbol{selNDI_{f,ndi}}\right\}+\sum_{di=1}^{numDI}\left\{\boldsymbol{selDI_{f,di}}\right\}\leq 1\quad for\ all\ \boldsymbol{f}$$

The constraint below indicates that an irrigation level (***$selDIWat_{f,s}$ = 1 for some* s**) is selected for a field only if a DI crop is grown in a field (***$selDI_{f,di}$ = 1 for some* di**).

For a field, if ***$selDI_{f,di}$*** = 0 for all **di** then ***$selDIWat_{f,s}$*** must be equal to zero for all **s**. Sum of ***$selDI_{f,di}$*** for all **di** has a maximum of one, so sum of ***$selDIWat_{f,s}$*** has a maximum of one.

$$\sum_{s=1}^{numDIWat}\left\{\boldsymbol{selDIWat_{f,s}}\right\}\leq\sum_{di=1}^{numDI}\left\{\boldsymbol{selDI_{f,di}}\right\}\quad for\ all\ \boldsymbol{f}$$

Crops must meet the farmer's minimum and maximum acreage:

$$minac_{ndi} \leq \sum_{f=1}^{numfld} \{fldsize_f \cdot \boldsymbol{selNDI_{f,ndi}}\} \leq maxac_{ndi} \quad for\ all\ \boldsymbol{ndi}$$

$$minac_{di} \leq \sum_{f=1}^{numfld} \{fldsize_f \cdot \boldsymbol{selDI_{f,di}}\} \leq maxac_{di} \quad for\ all\ \boldsymbol{di}$$

Farmer's minimum and/or maximum number of acres of fallow:

$$\boldsymbol{minac_{fallow}} \leq \sum_{\boldsymbol{f=1}}^{\boldsymbol{numfld}} \{\boldsymbol{fldsize_f} \cdot [\boldsymbol{1} - \boldsymbol{selNDI_{f,ndi}} - \boldsymbol{selDI_{f,di}}]\} \leq \boldsymbol{maxac_{fallow}}$$

Return from any crop must cover operating costs (NR > 0):

$$\sum_{ndi=1}^{numNDI} \{\boldsymbol{selNDI_{f,ndi}} \cdot \boldsymbol{NR_{f,ndi}}\} + \sum_{di=1}^{numDI} \{\boldsymbol{selDI_{f,di}} \cdot \boldsymbol{NR_{f,di}}\} \geq 0 \quad for\ all\ \boldsymbol{f}$$

OR the net return from any crop must be greater than the cost of fallow:

$$\sum_{ndi=1}^{numNDI} \{\boldsymbol{selNDI_{f,ndi}} \cdot \boldsymbol{NR_{f,ndi}}\} + \sum_{di=1}^{numDI} \{\boldsymbol{selDI_{f,di}} \cdot \boldsymbol{NR_{f,di}}\} \geq 0 \quad for\ all\ \boldsymbol{f}$$

Table 3. Model Input Variable Descriptions.

Name	***Units***	***Description***	***Type***
$falcost$	*$/ac*	*Cost of fallow*	*input*
$fc_{ndi\ or\ di}$	*$/ac*	*Fixed cost for growing crop* **di** *or crop* **ndi**	*input*
fic_f	*$/ac*	*Fixed cost of irrigation*	*input*
$fldsize_f$	*ac*	*Size of field* ***f***	*input*
$nfld$	*integer*	*Number of fields on the farm*	*input*
$minac_{ndi\ or\ di}$	*ac*	*Minimum number of acres of crop* **ndi** *or* **di** *that the grower will grow*	*input*
$maxac_{ndi\ or\ di}$	*ac*	*Maximum number of acres of crop* **ndi** *or* **di** *that the grower will grow*	*input*
$p_{ndi\ or\ di}$	*$/yield unit*	*Selling price of crop* **di** *or crop* **ndi**	*input*
Total available water	*ac-ft*	*Total amount of water that can be applied as irrigation*	*input*
$vc_{ndi\ or\ di}$	*$/yield unit*	*Costs for crop DI or NDI that depend on the yield (currently harvest costs)*	*input*
vic_f	*$/(ac-ft/ac)*	*Variable irrigation costs – depends on the amount of irrigation used*	*input*
$willDI_{f,di}$	*binary*	*1 if grower is willing to grow crop* **di** *in field* ***f;*** *0 otherwise*	*input*
$willNDI_{f,ndi}$	*binary*	*1 if grower is willing to grow crop* **ndi** *in field* ***f;*** *0 otherwise*	*input*

Table 4. Model Optimization Variable Descriptions.

Name	***Units***	***Description***	***Type***
$selDI_{f,di}$	*binary*	*1 if NDI crop* ***ndi*** *is selected for field* ***f****; 0 if not*	*decision variable*
$selDIWat_{f,s}$	*binary*	*1 if this level* ***s*** *of deficit irrigation is chosen for field* ***f****; 0 otherwise*	*decision variable*
$selNDI_{f,ndi}$	*binary*	*1 if NDI crop* ***ndi*** *is selected for field* ***f****; 0 if not*	*decision variable*
$\boldsymbol{NR_{farm}}$	*$/farm*	*Net return from farm*	*Objective*

Table 5. Model Component Variable Descriptions.

Name	***Units***	***Description***	***Type***
di	*index*	*Index for deficit irrigated crops*	*index*
f	*index*	*Index for field*	*index*
ndi	*index*	*Index for non-deficit irrigated crops includes fully-irrigated and dryland*	*index*
numDIWat	*index*	*Number of levels (s) of water production functions* ($ryld_s$~$rirr_s$)	*index*
s	*index*	*Index for levels (steps) of net irrigation that can be selected for a DI crop; also the index to the associated relative yield*	*index*
$aeff_f$	*proportion (no units)*	*Application efficiency for irrigation system on field f (water delivered to field*application efficiency is the water available to the crop) ;* $0 \leq aeff_f \leq 1$	*parameter*
$nir_{f,di}$	*ac-ft/ac*	*Seasonal net irrigation requirement for maximum yield of DI crop di in field f*	*parameter*
$nir_{f,ndi}$	*ac-ft/ac*	*Seasonal net irrigation requirement for NDI crop ndi; if ndi is a dryland crop then* $nir_{f,ndi} = 0$;	*parameter*
numDI	*integer*	*Number of DI crops in the model*	*parameter*
numNDI	*integer*	*Number of NDI crops in the model*	*parameter*
$rirr_{f,s}$	*proportion - no units*	*Relative irrigation in field f associated with s; This level is selected if* $SelDIWat_s = 1$. *Theoretically* $0 \leq rirr_s \leq 1$ *but we may put reasonable limits on it to help get the correct decisions*	*parameter*
$ryld_{f,s}$	*proportion – no units*	*Relative yield of crop di in field f as indexed by s;* $0 \leq ryld_{f,di,s} \leq 1$	*parameter*
$yld_{f,di}$	*yield units/ac*	*Maximum possible yield of crop DI in field f*	*parameter*
$yld_{f,ndi}$	*yield units/ac*	*Yield of crop ndi in field f (ndi crop may be fully irrigated or dryland crop)*	*parameter*
$\boldsymbol{NR_{f,di,s}}$	*\$/ac*	*Net return if DI crop di is grown on field f*	
$\boldsymbol{NR_{f,ndi}}$	*\$/ac*	*Net return if NDI crop ndi is grown on field f*	

Dryland crops are included within the optimization as NDI crops. Crop water production functions are handled as a simple lookup table for two reasons: 1) avoiding concerns of a linear versus non-linear function in the optimization, 2) water production functions from any source can be easily entered by the user and including crop product[on functions brought about by a farmer's personal experience gained from operating a plan. In a similar way, new crop varieties including trial varieties can be entered and considered.

CHAPTER 4
OPTIMIZATION OF ALTERNATIVE FARMING PRACTICES

4.1 A Brief Overview of Optimization Model Operation

The Model utilizes farmer-user inputs for the simulated farming operation to mathematically optimize future farming operations against a quantified or presumed consumptive use water budget for the farm. Default data are available with the program data base as extracted from the National Agricultural Statics Service (http://www.nass.usda.gov/). A successful run of the model constitutes a "scenario" that can be evaluated.

The farm simulation input is easy to use by simple point and click entry of boundaries over the top of aerial imagery to outline the farm itself and existing or proposed fields, then inputs such as planned "willing to grow" crops and practices are added. When finished, the farmer has a precise computer-generated map of the farm that becomes the basis for planning and running scenarios.

Inputs include fields (up to 20 fields), acceptable crops and irrigation practices that the farmer is willing to consider by field (up to 18 combinations). Practices for farmer-consideration include full irrigation, deficit irrigation, dryland crops, and fallowing. Default values for crop market price and per crop input costs are used or any of the default inputs can be changed as may be desirable from the farmer's experience or perspective.

With input entry completed, a mathematical optimization is performed as based on those inputs to provide a scenario that can be named and saved. Optimization output data compares historical net revenues with the forecast of net revenues based on the scenario. The forecast of net revenues will likely be less than the historic net revenues but the lease value of the consumptive use water is forecast as well. The lease value of the water, when added to the forecast net revenues, will likely exceed the historic net return.

4.2 Model Inputs

The end user of this Model is anticipated to be a farmer and not an engineer or expert in the use of the model. The presumption and basis for the user interface is that a farmer user will need a "friendly" interface and an interface that does not require much financial data collection beyond what a farmer inherently knows about their own operations without searching back in the years and finding background financial files or data. Further, the mathematical underpinning of the Model is intended to be completely behind the scenes and essentially veiled by the user interface. Most farmer users do not care about the inner workings of the Model but want believable and understandable results against which they can do some "what if" thinking and make decisions about the pending cropping year.

The initial goals associated with development of a farm simulation and optimization model (The Model) include:

1) Application of a proprietary and robust optimization engine to avoid redundantly developing such from the beginning but also to utilize the input features inherent in this new generation of application programs. (The selected engine is Frontline Systems Risk Analysis Platform or Premium Solver Platform.)

2) Available default values to assist the farmer user with ease of data entry and a shallow learning curve to familiarize with the Model and hence the System.

3) Fast and predictable solutions (convergence) that reflect practical aspects of problem solving needs and avoid farmer user confusion with no solution, multiple solutions, or non-optimal solutions.

4) Data inputs and an initial Model run, say within approximately one hour of familiarization, by a user who has no experience with optimization algorithms, routines, or even terminology.

5) Readable and intuitive assistance in the form of context sensitive help or user instructions.

6) Ability to migrate the Model from an Excel spreadsheet file into a web interface.

Several screen captures exemplify the user experiences in exercising the model as found in the web-delivered and server based program offering. Figure 14 shows the geographic information system (GIS) style field data entry screen. The user does not need to know GIS program or input features in order to input field data into the system. Data entry is facilitated by using intuitive point and click tools. Field boundaries can be input, color coded, named, and resultant acreage returned. The input screen can be set up to show attributes of interest by picking suitable attributes from the list on the left.

Figure 15 shows the user interface for inputs of crops that the farmer is willing to grow along with the acceptability, or not, of certain practices to the farmer. Also, note the input of maximum and minimum acreage for both irrigated and dryland crops on this input screen.

Figure 16 shows the reported results of the optimization run and indicate the projected net return given the farmer inputs.

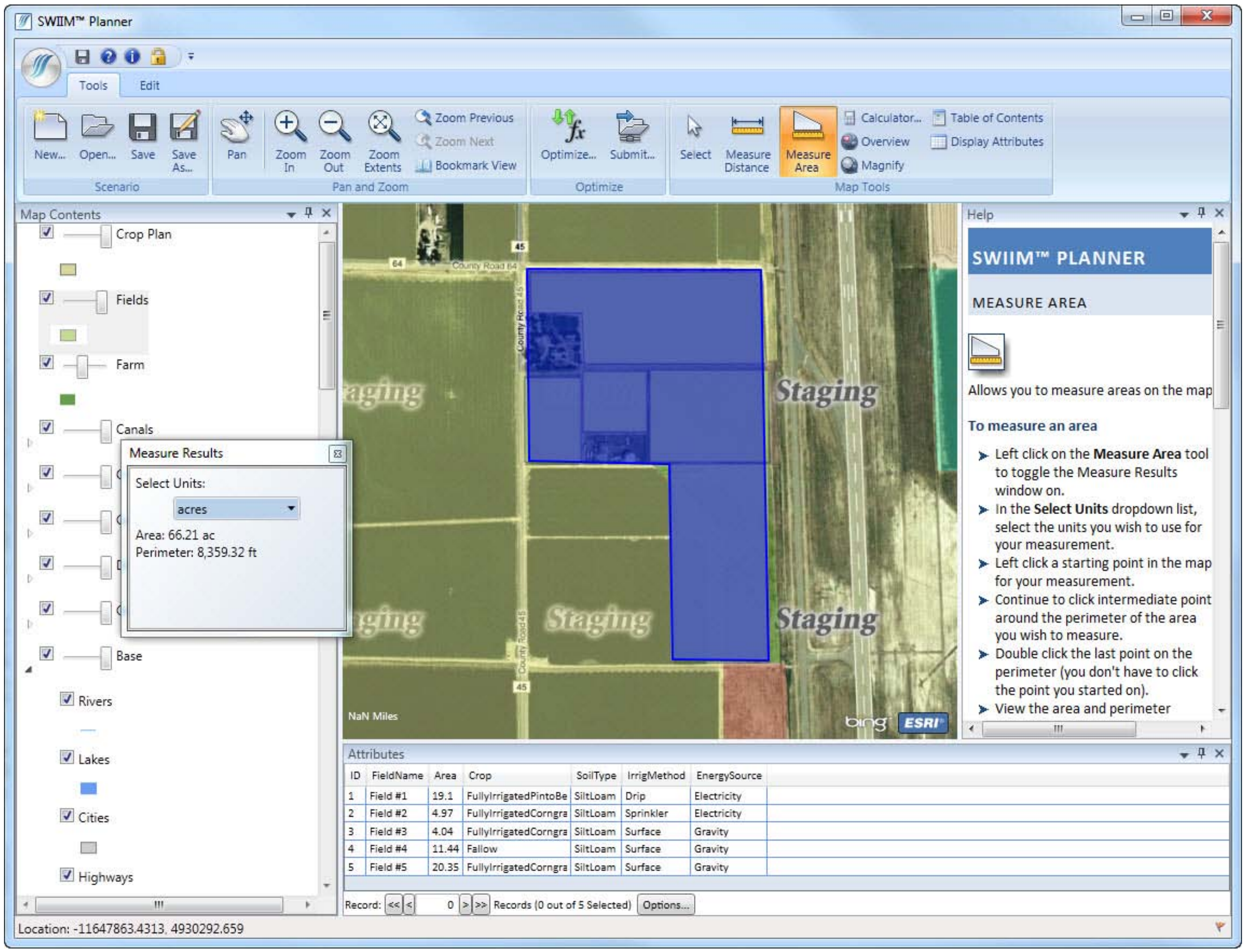

Figure 14. Optimization program GIS-like data entry screen.

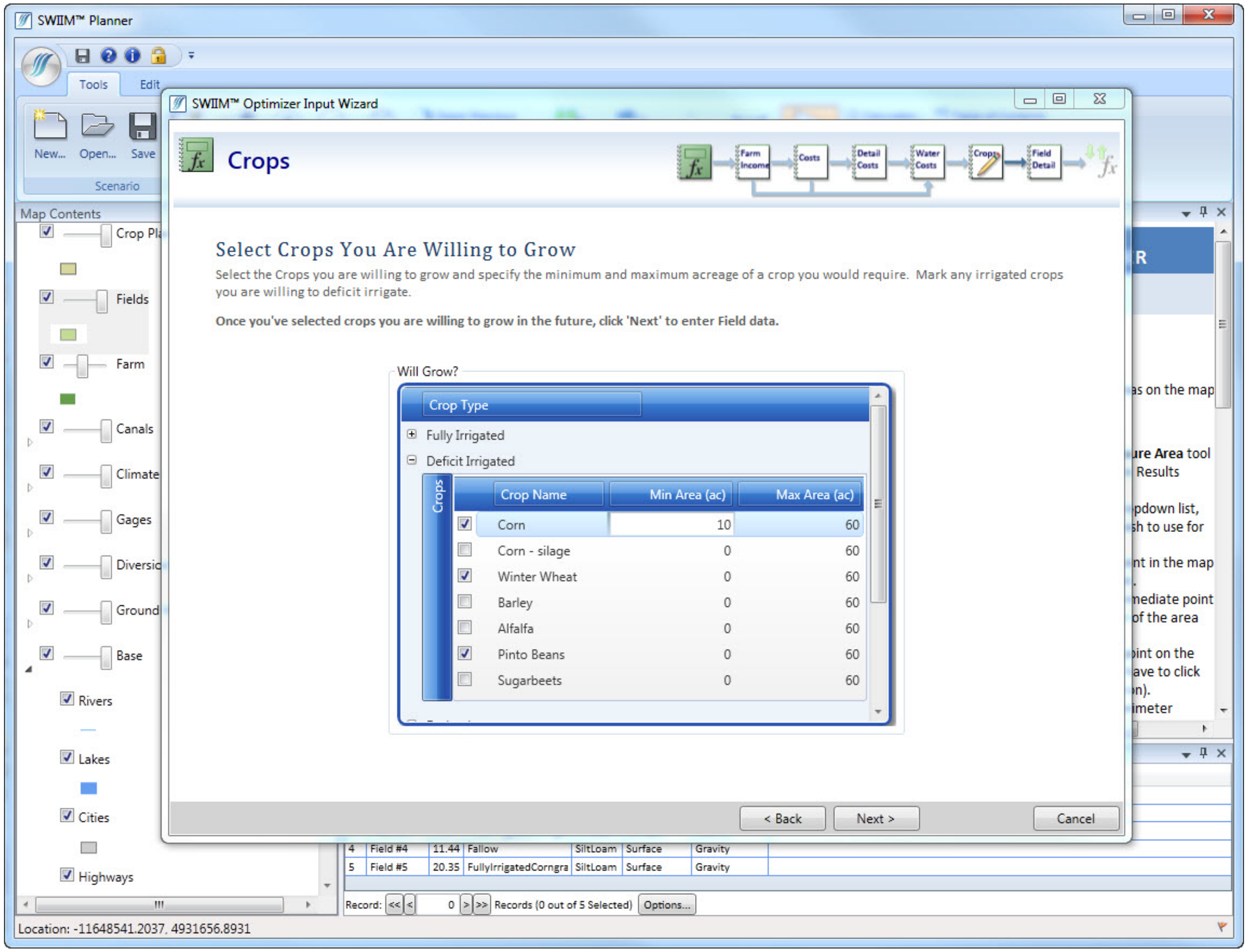

Figure 15. Optimization program input screen for crops and acceptable practices.

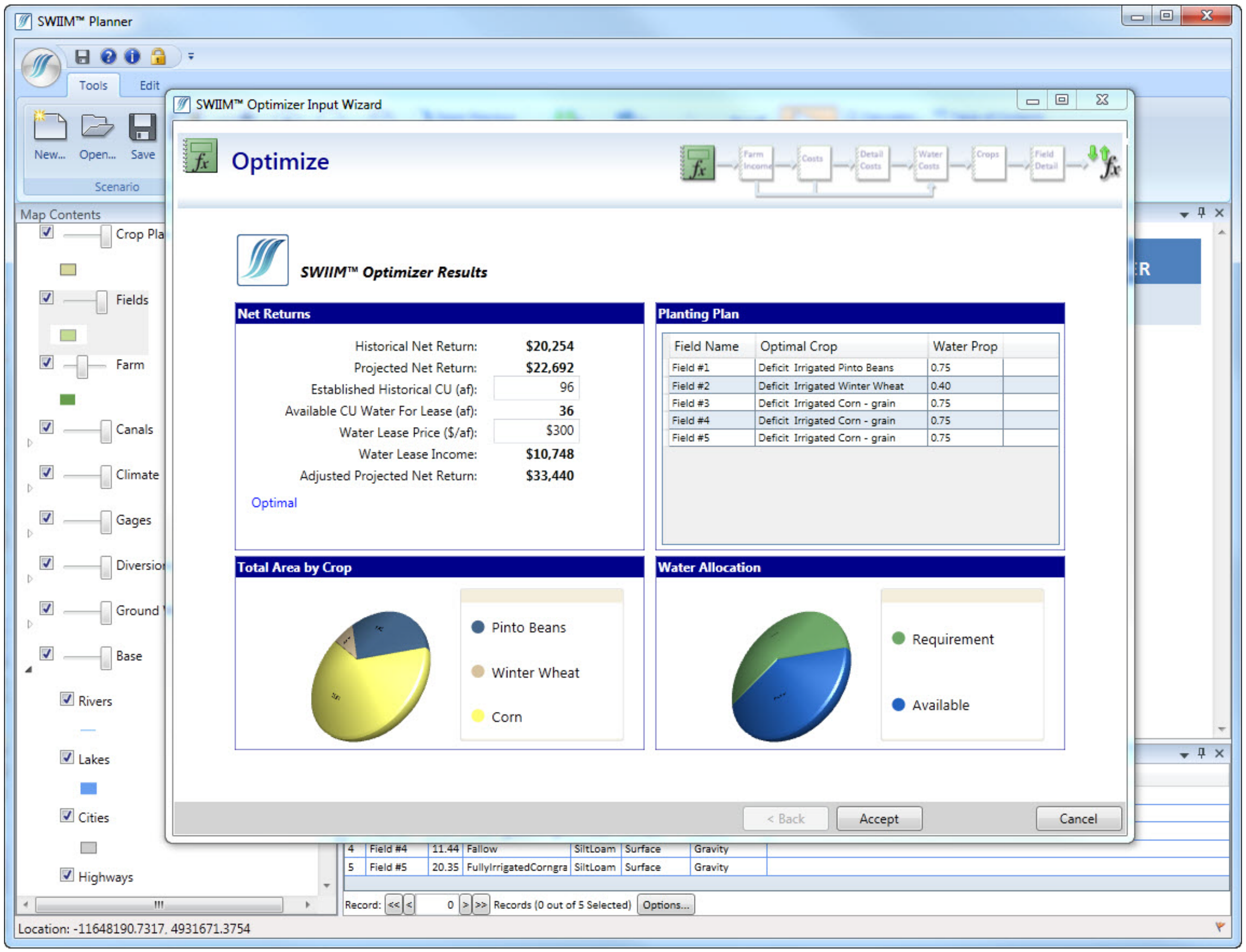

Figure 16. Optimization program output report screen indicating the modeled net returns based on user inputs.

4.3 Lessons Learned and Truisms Extrapolated from Multiple Model Runs

Exercising of the Model has been initiated and accomplished for multiple purposes to include: 1) error checking and 2) program logic problem identification. Naïve users have been commissioned as well to run the Model and help identify any problems with downloading or using the program from the "naïve" standpoint of not understanding farming operations or optimization schemes. Whether doing error checking or beta testing of software, it is good practice to make multiple runs with naïve inputs and potentially naïve users to identify and trap errors or even unidentified program logic problems.

Multiple exemplary farming situations complete with all program inputs (program scenarios) have been conceptualized and initiated to assist with the testing and output comparison to lead to definition of potential truisms.

Primary inputs into the Model can be classified generally as 1) crops (willing to grow, selected crops), 2) crop input costs, 3) crop prices, 4) yields, 5) soils, and 6) the irrigation water allotted to the farm.

Exemplary situations can be conceptualized and constructed in a framework. One example of a framework is as follows:

- Crops (limit selection to two)
- Input costs (hold to default data)

- Crop prices (adjust through a suitable range)
- Crop yields (hold to default data)
- Water (adjust through a suitable range of lease contract unit cost, $ per CU AF)

An example of a naïve Model run in shown in Table 6. Total farm acreage was selected to be 640 acres or one square mile (one section). Four fields were conceptualized of equal size. Two crops are considered – corn and wheat. Crop prices for corn and wheat, respectively, were adjusted to create multiple price levels at 0.5 x default value, default value, and 2x default value. Water allocation to the farming operation was varied at multiple levels as well. The results shown in Table 6 are indicative of the results obtained.

Table 6. Example of Naïve Model Runs using a Standardized Framework.

Naïve Scenario considering Crop Price Sensitivity

Avg Price of Corn	*3.00*	*$/bu*
Avg Price of Wheat	*3.98*	*$/bu*
Wtr. Req. Corn/Silt Loam	*18.36*	*in/season*
Wtr. Req. Wheat/Silt Loai	*10.26*	*in/season*
Efficiency (Surface Irr)	*0.55*	
Irr. Req. Corn/Silt Loam	*2.78*	*ft/season*
Irr. Req. Wheat/Silt Loam	*1.55*	*ft/season*
Established Historic CU	*1,024*	*ac-ft*
Water Lease Price	*$ 250*	
Water Proportion (1.0)	***1960***	*ac-ft*

Farm	640 ac
Four Fields	160 ac each
Two Crops	Deficit Irrigated Corn
	Deficit Irrigated Wheat

	Price ($)	Proportion of Avg	Irrigation Proportion (X if no crop selected) Field #1	Field #2	Field #3	Field #4	Historic Net Return ($)	Projected Net Return ($)	Irrigation Req'd (af)	Available CU (af)	Return Flow Obligation (af)	Lease Income ($)	Adjusted Projected Net Return ($)
Corn	1.50	0.50	x	x	x	x	$ (104,577)	$ -	-	1,024	838	$ 256,000	$ 256,000
Wheat	1.99	0.50	x	x	x	x							
Corn	1.50	0.50	x	x	x	x	$ (104,577)	$ 18,078	895	529	433	$ 132,160	$ 150,238
Wheat	2.99	0.75	0.9	0.9	0.9	0.9							
Corn	1.50	0.50	x	x	x	x	$ (104,577)	$ 62,093	895	529	433	$ 132,160	$ 194,253
Wheat	3.98	1.00	0.9	0.9	0.9	0.9							
Corn	3.00	1.00	1	1	1	1	$ 68,223	$ 68,223	1,780	45	37	$ 11,200	$ 79,423
Wheat	3.98	1.00	x	x	x	x							
Corn	3.00	1.00	x	x	x	x	$ 68,223	$ 239,895	995	474	388	$ 118,400	$ 358,295
Wheat	7.96	2.00	1	1	1	1							
Corn	6.00	2.00	1	1	1	1	$ 413,823	$ 413,823	1,780	45	37	$ 11,200	$ 425,023
Wheat	7.96	2.00	x	x	x	x							

4.4 Analysis of a Profitable Going Concern Farm Operation

Oftentimes, an analysis of the far ends of a decision continuum is indicative of, or framing of, the context for understanding of important issues. With this in mind, and without even using the optimization routines described here, consideration was given to a successful and long term farming operation growing a high cash value crop. The question is “would a successful, high cash value farming operation even consider, from the purely financial perspective, a parting off part of a proportion of their CU water?”

Consider Farmer H. Farmer H grows carrots on the South Platte River. Based on an internet search of USDA statistics for Colorado carrot production, the production summary shown in Table 7 was compiled.

Using the averages annual averages in Table 7, 3662 acres planted with 3300 acres harvested. $15.632m divided by 3300 acres, so $4,737 gross revenue per acre. In the case of a long term going concern, assume the net return is 30% of the gross revenue or $1420 / acre. Assume also that it annually takes 2.5 feet of water per acre to grow carrots. Assume that under Farmer H’s water right, the historic CU is 0.83 AF / acre. This assumption is based on (HRS Water Consultants 2010).

Table 7. Carrot Production Value in Colorado.

Year		Acreage		Yield	Production	Farm value	
		Planted	Harvested			Per unit	Total
		-- Acres --		*Cwt*	*1,000 cwt*	*$/cwt*	*$1,000*
1992		2,700	2,600	365	949	10.60	10,059
1993		3,300	2,800	380	1,064	8.60	9,150
1994		3,500	3,100	380	1,178	10.00	11,780
1995		4,000	3,600	475	1,710	13.50	23,085
1996		4,300	4,100	350	1,435	7.10	10,189
1997		5,400	4,800	500	2,400	10.00	24,000
1998		4,400	4,000	400	1,600	10.60	16,960
1999		3,900	3,700	500	1,850	9.70	17,945
2000		4,300	4,100	550	2,255	9.60	21,648
2001		3,700	3,200	660	2,112	10.00	21,120
2002		3,300	2,800	500	1,400	10.20	14,280
2003		2,700	2,400	480	1,152	10.30	11,866
2004	2/	2,100	1,700	630	1,071	10.40	11,138
		3662	**3300**	**475**	**1552**	**10.05**	**15,632**

Now, consider a 100-acre field that Farmer H might consider bringing under a changed practices and optimization scheme. $4737 / acre X 100 acres = $473,700 in gross revenue and $142,100 in net return. Farmer H will probably convert the field to a different crop -- say corn for discussion. So, now Farmer H's input costs will drop but also the net return will drop dramatically.

If Farmer H gave up half of quantified CU water, that would be 0.83 AF of CU X 100 acres but divided by 2. So, the value of the water at $500 per AF of CU might be $20,750. Farmer H must change to a suitable crop like the corn to accomplish that.

But maybe Farmer H cuts his CU water on the 100 acres to zero with a permanent fallowing plan on that field. Farmer H's input costs drop further but so does Farmer H's net return. However, Farmer H now has $41,500 in risk free revenue from leasing the CU water. Is that enough to make Farmer H take notice? – not likely in consideration of the historically profitable use of that 100 acre field and water right.

A key point in this going concern analysis is that this ground is presumed fertile and suitable for growing carrots. Farmer H's whole operation is predicated on growing carrots and this carrot production feeds a value-added carrot processing operation as well. Because Farmer H been farming this ground for 50 years, the ground is likely paid off. Much of the equipment is paid off as well. Because of low fixed annual costs, the net return on the 100 acres may be pretty close to equal to the profit on the 100 acres. So, the actual profit potential may be $142,100 on the 100 acres. It would seem likely that Farmer H will not want to consider a $41,500 revenue stream (fallowing of the full field) to compare to a $142,110 revenue stream.

The summary point is this: existing farm operations with high cash value crops and long-term going-concern high net returns are not likely to participate in a water transfer involving a proportional parting off of CU unless the operation wants to downsize or go out of business for some unknown business factors.

Similarly, farmers who are suitably compensated considering a high and sustainable commodity pricing will likely envision staying in farming but they may appreciate a proportional parting off of the CU water based on the likelihood of continued higher commodity price levels and a subjective evaluation of risks (Whaley 2010).

4.5 Comparison between the Model and Other Programs

An feature analysis and comparison of several programs intended for farmer use in evaluating lease programs potential or water allocations. AgLET and Water Optimizer (described in Chapter 2) and the Model (described in Chapter 3 and 4) are contrasted in Table 8.

Table 8. Feature Comparison between Selected Programs.

Comparative Feature	**AgLET**	**Water Optimizer**	**Model (as described herein)**
Delivery approach	Excel file	Excel file	Internet download, server based delivery
User interface	Excel spreadsheet	Excel spreadsheet	Task specific web page
Primary program objective	Evaluate fallowing and water leasing as an option in future farming operations	Prediction crop yields under limited water scenarios	Optimize multiple farming practices against a consumptive use water budget
Mathematical optimization	No	Yes, MS Excel Solver	Yes, MS Excel Premium Solver and Front Line Systems SDK

CHAPTER 5
IMPLEMENTATION PERSPECTIVES

If farmers exercise the optimization model described in Chapter 4 and like the perceived opportunity and the forecast of future farming operations based on changed practices, then it is important to have implementation concepts identified and demonstrable. This chapter describes in detail what implementation will look like, and further, recommends next steps for specific project implementation and proof for the concepts described.

5.1 Supervisory Control and Data Acquisition (SCADA) and Related Instrumentation

SCADA is fundamental to implementation of the concepts described here. Without SCADA, and in fact, affordably priced SCADA, the implementation of a lease program intended to part off a proportional amount of CU water and satisfy the objectors and the State Engineer's Office in a changed decree would not even be practical. The costs of the program implementation would exceed the revenue benefits of the parted off CU water.

SCADA is an acronym for Supervisory Control and Data Acquisition. SCADA has been a viable technology for 40 years but mostly with industrial process control and monitoring demands that could afford the technology. Irrigation, for many years, was not an industry that warranted the high hardware and software cost until some irrigation manufacturers began to develop a specialized type of SCADA from their own proprietary hardware and software. In the mid 1980's, adapted SCADA systems that were specifically intended for irrigation projects that could afford it – landscape and golf irrigation – came into existence. During this period, specialized SCADA systems found a niche in irrigation. Those systems, by a myriad of different proprietary names, have now been available for approximately 30 years.

Where was agricultural irrigation to be found in this picture? There were a few irrigation central control systems to be found in agriculture, but comparatively few. Agriculture could generally not afford the cost. During the early 1990's, the cost of implementing SCADA on a per site basis was in the range of $5,000 to $10,000 per site even without adding any hydraulic gate actuation hardware. This cost was quite high in comparison to the cost of a classic chart recorder installation on a weir or flume, or for that matter, the cost of manual actuation of valves, headgates, and checks by the canal company's ditch rider.

The current cost of SCADA implementation has decreased in recent years to a price point where SCADA is affordable to canal and mutual irrigation companies. SCADA can provide many cost effective features which result in significantly improved canal operations, improved deliveries to shareholders, and reduced liabilities. If a mutual irrigation company or irrigation district is to get involved in managing a water leasing program for their shareholders, the monitoring could be added to an existing SCADA system or the leasing program may even drive an initial SCADA installation.

Generic definitions are appropriate to help describe basic SCADA concepts. The “central system” is a microcomputer-based and interface software used to communicate with remote sites. The software that provides an umbrella over everything is called a “human-machine interface” or HMI. The key hardware at remote sites is a “remote terminal unit” or RTU.

The HMI software can be proprietary and published by the manufacturer of the hardware, or it can be more generic and published by software companies that write more generic HMI programs that are compatible with the hardware of many manufacturers. Flexible and broadly compatible software application programs are known as Wonderware, Lookout, and Intellution, as examples.

Communication can be via wire line (hard wired), telephone, fiber optics, or radio. Radio for most canal operations and agriculture operations is preferred, although the availability of a canal easement does present the potential for easy fiber optic installation. The SCADA industry has been standardized largely on a communication protocol called “Modbus” which is quite flexible for most SCADA applications. Modbus has become a commonly accepted standard protocol (Halm 2010).

Remote terminal units are essentially a computer that can be programmed for the specific requirements at individual sites. The RTU is also generally the point at which sensors are connected. A site with only one requirement, *e.g.* monitoring the water surface elevation in a flume or weir, would have a water level sensor wired to it. The RTU then communicates to the central system, or conversely, the central system can initiate a time-driven call to the RTU. The RTU can be monitoring one or more sensors, perform logical operations, and create an exception report or alarm. If flows or water levels exceed a pre-set limit at a point in the canal system, an alarm can be raised or action can be taken in the form of gate or check adjustments. Alarms can appear at the central computer or even be transmitted to a cell phone or pager.

There are multiple levels at which SCADA can be implemented. Beginning with monitoring only, and then expanding the initial system to other sites and adding capability and features to sites is quite appropriate.

Four levels of SCADA implementation can be described by their respective function and utility:

- Monitoring (only).
- Remote manual operations.
- Local control.
- Fully automated operations.

Each level results in increasing capability within the SCADA system, but each level costs more. The additional cost is largely at the remote sites, not at the central computer. The central workstation computer becomes a fixed cost except for HMI upgrades and the inevitable computer hardware upgrades.

The minimum SCADA requirement for the implementation phase of the lease program requirements described here is the lowest cost, monitoring level. A recent investigation of available RTUs indicates that installed unit prices, and including a water surface level sensor, have dropped to the range of $4,000 to $5,000 including an enclosure and solar panel (Halm 2010).

Soil moisture sensors are envisioned to be a key instrumentation component of a water leasing program. The purpose of soil moisture sensors would be twofold:

1) Soil moisture monitoring to predict when the next irrigation should occur (i.e. soil moisture based irrigation scheduling).

2) Monitoring to understand at least the fact of, or the lack of, subsurface moisture movement below the root zone which would indicate subsurface return flows.

Stacked sensors on a vertical soil moisture sensing strip provides flexibility for sensors to be located both within and below the root zone depths. These sensors are made by several manufacturers and are available and affordable. Figure 17 shows a recent test installation for testing of this technology having sensors down to the 7-foot level (Arnold 2010). Data is collected every half hour, uploaded using an AT&T cell phone modem, and posted to a password protected and user-configured website.

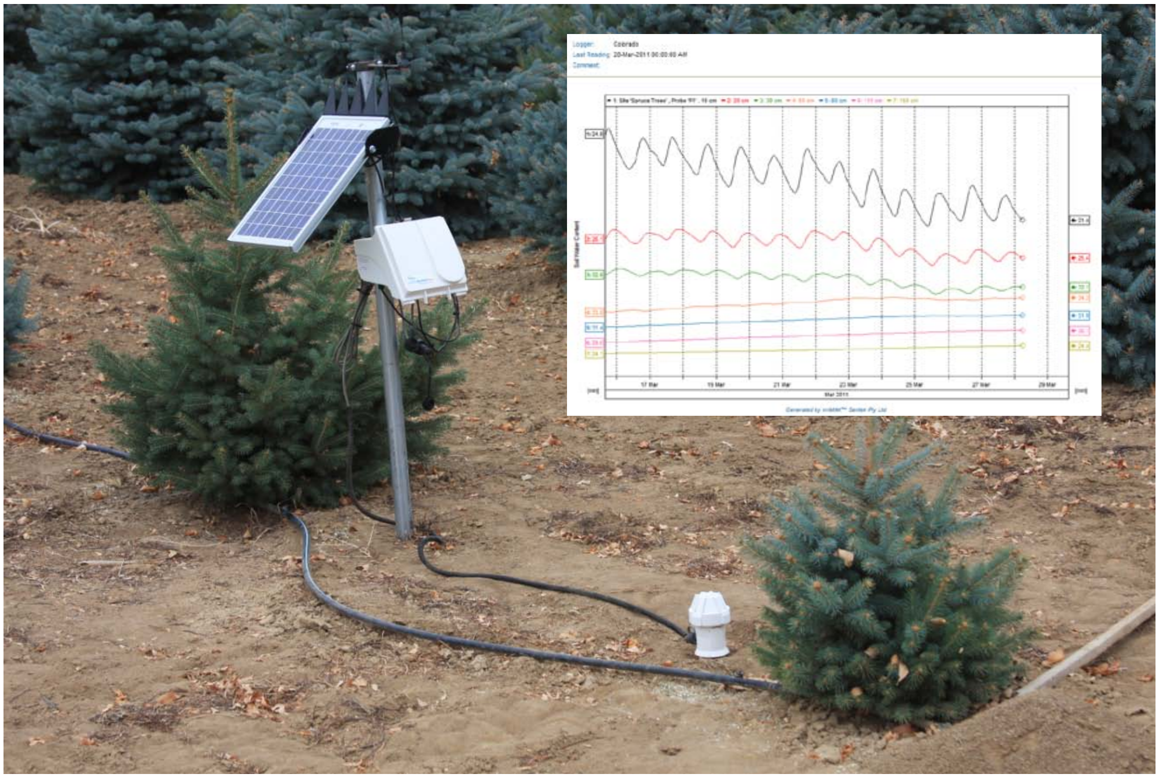

Figure 17. A Sentek manufactured capacitance soil moisture monitoring site installed in a configuration testing circumstance. Data for relative soil moisture levels over time and with depth are shown in the inset.

5.2 Recommendations for a Fully Featured Software System

In developing the optimization approach and Model described in Chapters 3 and 4, it is beneficial to think ahead to development and implementation of a fully featured program. Such a program would allow a user to first evaluate the potential for changed farming practices in their operation and then, if they determine to proceed, the same program would become the basis for monitoring and reporting of water deliveries, seasonal water balances, and return flows to the river.

Features of a completed software program to support the impositions of the change case decree or a substitute water supply plan would logically include:

- A package of technologies under one umbrella of software.
- A decision support system (DSS).
- A farm operations simulation.
- An optimization program for evaluating alternative farm operational strategies and potential for changed practices.
- A tool for evaluating a proportional parting off of consumptive use water.
- A means of developing and monitoring an annual water use budget.
- A database for cataloging historical and current operations of substitute water supply plans or change case decrees.
- A monitoring and reporting system following strategy implementation.
- A year-to-year planning tool for pending annual operations against a water budget.

Figure 18 shows, in an overview characterization, the elements of concept implementation that are assumed to be required under the terms of a change decree and subsequent oversight from the State Engineers Office. Computer based monitoring is shown at the farmstead, and collected data are continuously gathered and stored to a database on a server. Various fields are shown to include full irrigation, deficit irrigation, and new fully irrigated tree and vegetable crops. A field is shown to be permanently fallowed. A recharge pond is shown as a means of meeting historic subsurface return flow obligations. Low elevation aerial photography provides for affirmation of deficit irrigation and stressed crops. High elevation satellite imagery (NASA's LandSat) also validates and confirms the fact of stressed crops. See http://landsat.gsfc.nasa.gov/images/.

It is assumed that affirming ground truth observations and measurements will be required by a change decree. Operational reports from all instrumentation and data trending is envisioned to be reported as follows:

- Reports to farm management in consideration of water budgets and irrigation scheduling recommendations.
- Reports to the ditch company or farm cooperative in consideration of full System water budgets.
- Reports to the State Engineer in consideration of decree oversight and monitoring.

A least with the reports to the State Engineer, transparency and ready on-demand, internet access to data will be important. Automatic collection of data on a near real time basis and accumulation of that data in a single-source location is assumed. Appropriate trending is also assumed. Reports on demand, delivered transparently, time stamped data, and redundantly confirmed data will all help the State of Colorado's Water Resources staff accept an increased level of data collection and avoid concerns that a fully implemented system is an imposition on the State or State employees.

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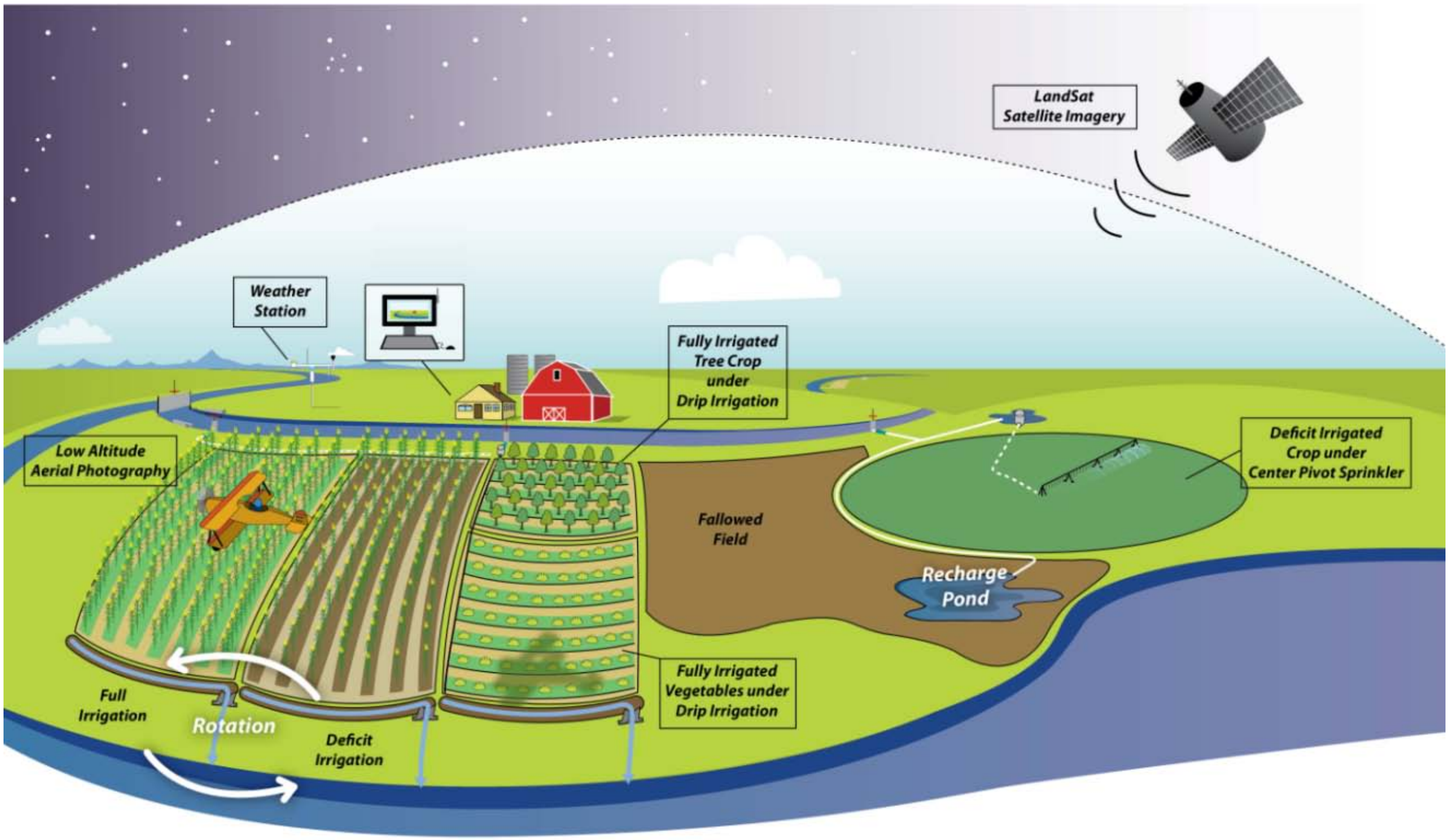

Figure 18. A characterization of a full single-farm System employing changed practices with measurement and monitoring to support a water right change case.

5.3 Water Balance at the Ditch Company Level

As was noted previously, the perspective of the ditch company or a farmer cooperative will likely be important in implementation of a water leasing program. This concept is portrayed conceptually in Figure 20. The planned operations will, of course, build from existing flow measurement structures that may already be in place to measure water deliveries or return flows. For example, this would include flow measurement at farm turnouts. However, observing the current scrutiny of change cases and the likely impositions of a changed decree, it is prudent to anticipate an increased level of data collection requirement to support the future operations of the change case and any water leasing plan. The data would support transparent monitoring of flows and return flows and document operations in accordance with the decree.

Additional flumes, weirs, and water meters are likely needed in many or even most circumstances. Figure 19 shows a particular type of long throated flume (aka Replogle Flume) with SCADA hardware and water surface level monitoring that is most flexible for vary flow conditions. This trapezoidal flume configuration can be designed for maximum accuracy over a wide range of flows (Clemmens et al. 2010) as in measuring the seasonal variations in return flows from irrigation. Design of these flumes is facilitated using a software program called Winflume found at http://www.usbr.gov/pmts/hydraulics_lab/winflume/ .

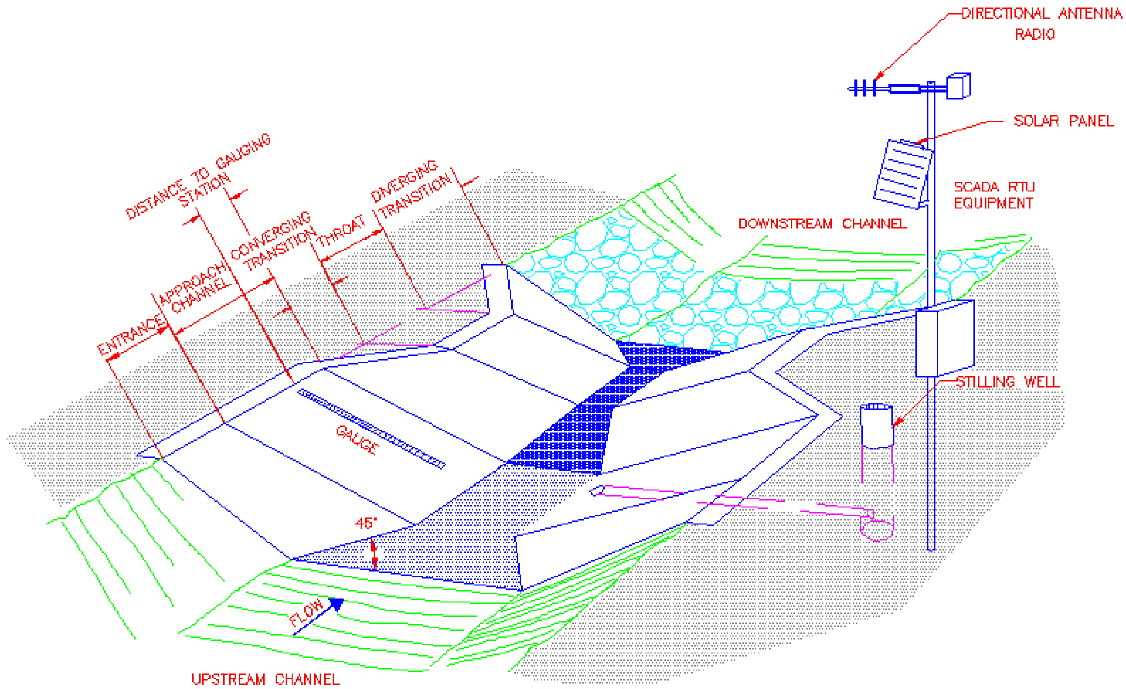

Figure 19. A long throated trapezoidal flume with SCADA hardware

Figure 20 shows generic elements of the operational water balance that would likely surround a farm, or farms, subjected to new data collection, data monitoring, and data reporting requirements.

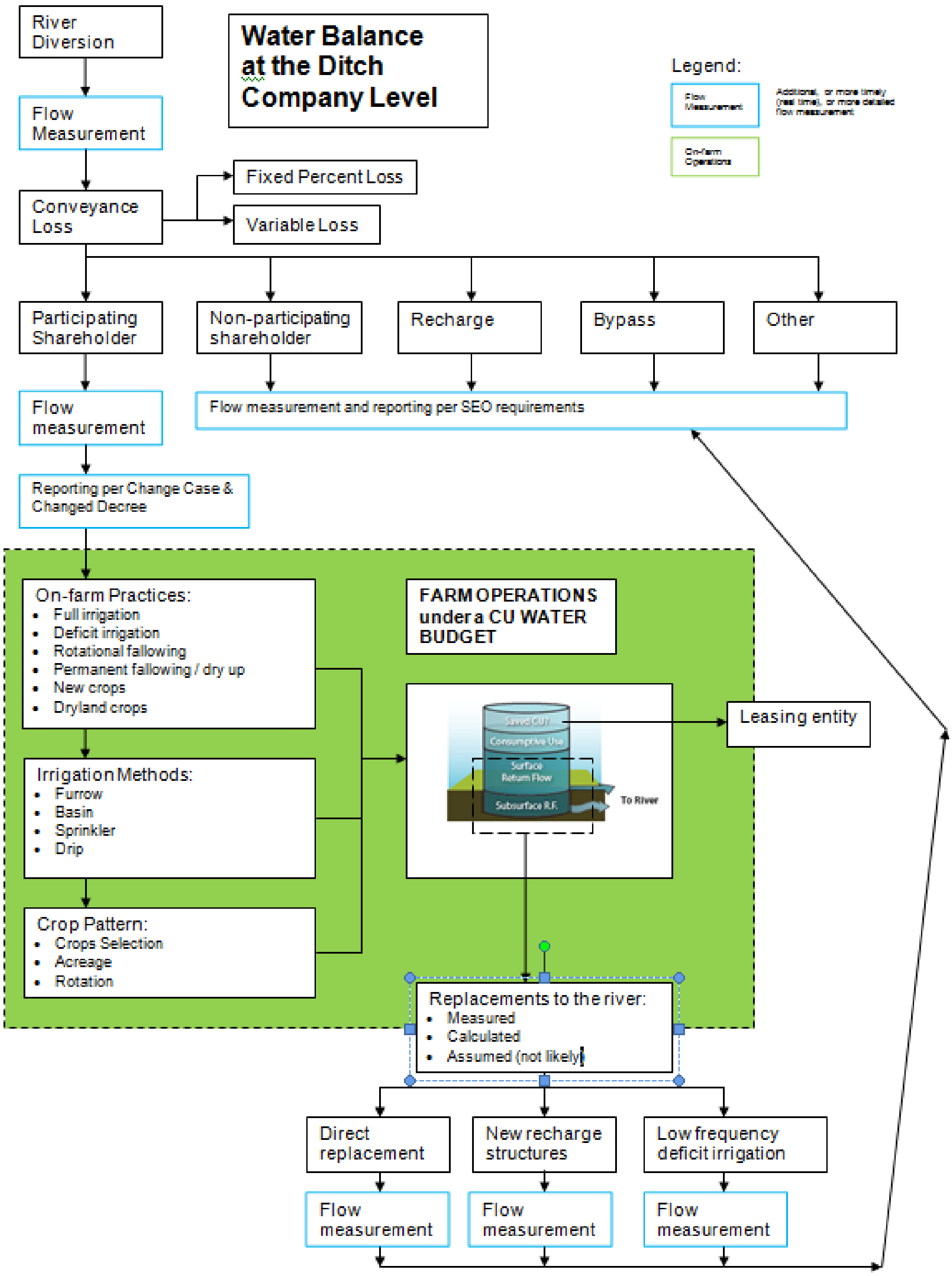

Figure 20. Depiction of water balance elements at the ditch company level.

5.4 Recommendations for Proof of Concept Implementation

One way to fully vet the concepts described is to implement an actual, albeit small, demonstration of the full system to include monitoring of delivered flow and return flows. Such an implementation could take place on quite a few of the river diversion on the South Platte. The elements that would need to be in place are:

- A water right holder with an interest in the concept and a willing participant in a proof of concept project.
- Likewise, a water user with an interest and a presumed real need for the water even if it is a somewhat manufactured need for the proof of concept year.
- An entity that will pay for, or cost share, the proof of concept implementation costs.
- Ability to transfer water from the leasor to the lessee with existing delivery infrastructure.

Table 9 indicates a short list group of river diversions in the South Platte Basin that appear to have potential as proof of concept diversions.

Table 9. Diversions on the South Platte with Proof of Concept Potential.

Shorthand Name	Formal Name	Irrigated Acres (acre)	Annual Average Diversion (AF)	Decreed or Reported Consumptive Use per Share (AF/share)	Potential Leesee:
New Cache	New Cache La Poudre Irrigating Co.	33,000	45,000	0.83 AF/acre	Fort Collins, Greeley, Windsor, Evans
Lake Canal	Lake Canal Co.	5,400	11,400	no ditch-wide in progress	Fort Collins
Super Ditch Co.	Super Ditch Co.	?	600,000	varies by ditch company	Longs Peak Water Authority
Union Ditch	Union Ditch Co.	5,000	29,000	approx. 30 AF / Union share	Aurora, Longmont
Lower Latham		10,000	38,000		
Western Mutual		7,100	20,000		
Farmers Independent		6,500	16,800		
Riverside ID	Riverside Irrigation District	24,000	53,000		
Bijou		28,000	48,500		
Harmony Ditch	Harmony Ditch #1	5,000	34,800		
Sterling		7,300	24,000		
Upper Beaver		9,800	31,000		
Lower Beaver		12,000	25,000		
Larimer & Weld		50,000	76,000		
Hillsborough		5,500	16,500		Loveland
Lower Boulder		3,400	20,500		
Highland	Highland Ditch Co.	28,000	41,500		Longmont
Louden	Louden IC&RC	4,000	13,500		Loveland
NPIC	North Poudre Irrigation Co.	?	?		Fort Collins

After scrutiny of the diversions listed in Table 9, two have come under additional scrutiny for suitable circumstances to allow for a vetting of and validation of approach and concept validation as early as 2011. It is recommended that these opportunities be further evaluated and receive consideration as proof of concept participants:

- Platte Valley Irrigation Co. Augmentation Group (diverts water from the South Platte near La Salle, Colorado)
- Lake Canal Company (diverts water from the Poudre River north of Fort Collins, Colorado)

The Lake Canal Company's service area is depicted in Figure 21. Lake Canal holds a fairly junior river decree on the Poudre River and diverts water at a diversion structure on the river in north Fort Collins. Farmers under the Lake Canal system generally utilize a junior direct flow right, storage rights from one or more of several other companies, and C-BT water from Northern Water. Some farmers also have augmented wells. As conceptualized the proof of concept would be accomplished with a small portion of the direct flow right in the May to June timeframe when Lake Canal's river decree is typically in priority. The water sources of farms or developments under the Lake Canal system are also shown Figure 21 with a bar representing the number of shares from each water source.

5.5 Exemplary Farm Layout

Figure 22 shows the concept of a farm layout as representative of many 350 acre farms in the South Platte Basin. Water measurement devices, sensors and SCADA hardware needed to monitor this conceptual farm is estimated to cost approximately $20,000. This cost could be born by:

1) The water borrower(s) in a lease arrangement.
2) The farmer.
3) Proportional sharing of costs between 1) and 2).
4) Cost sharing using NRCS EQIP contract funds.

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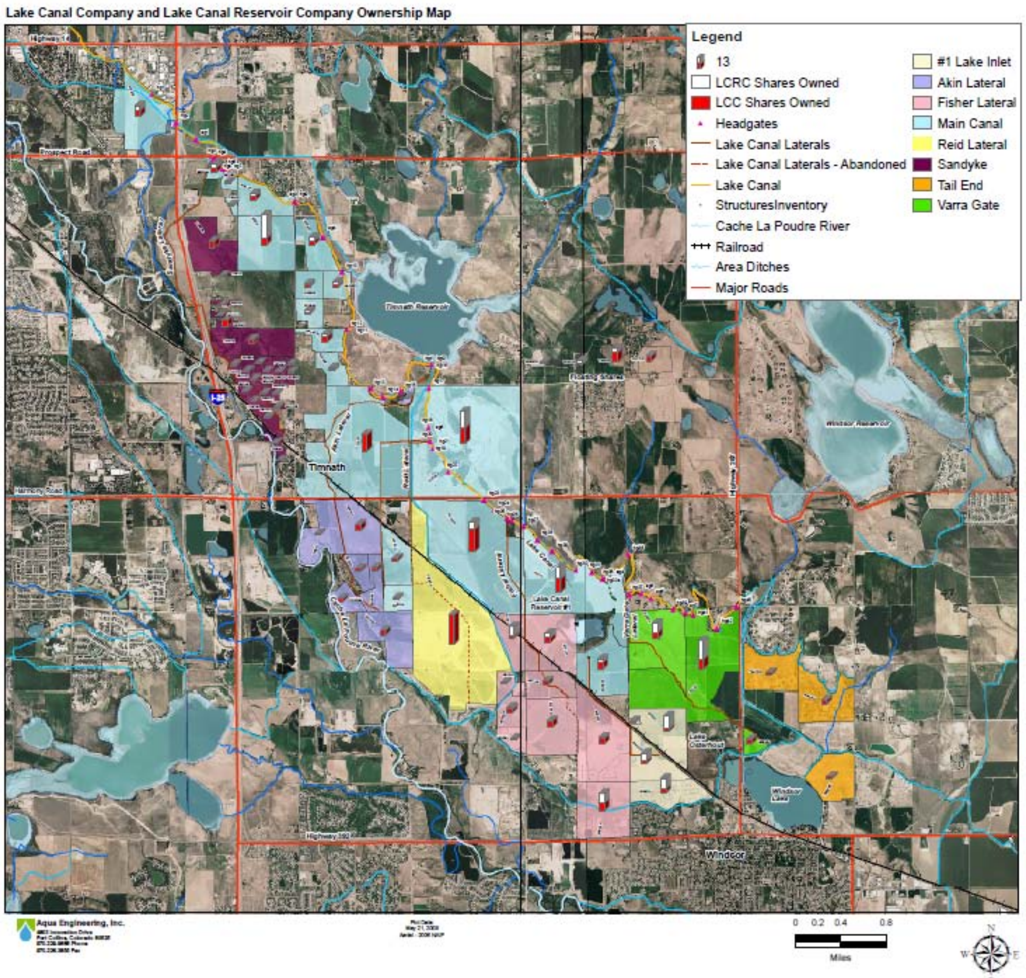

Figure 21. Lake Canal service area and share ownership by property.

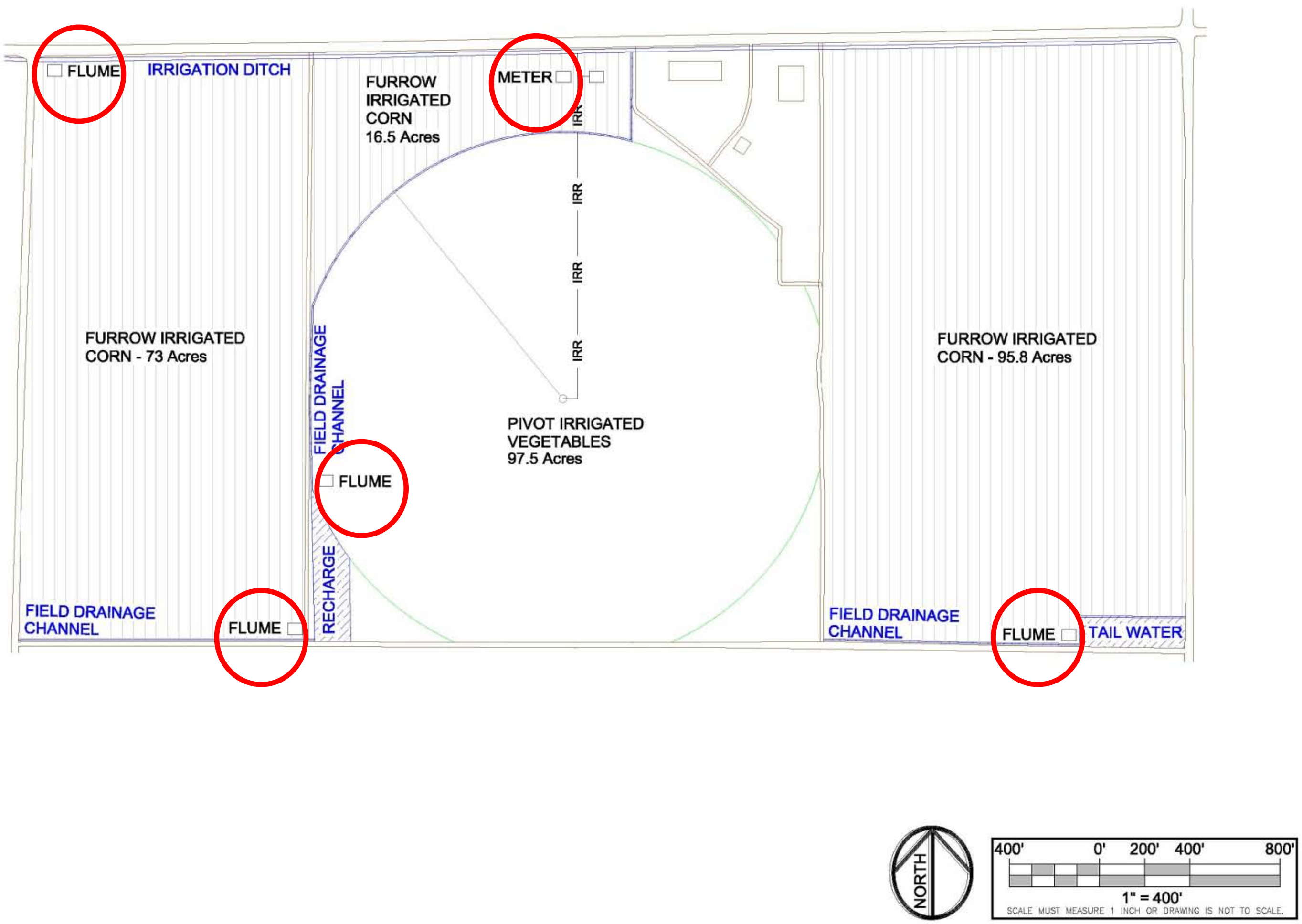

Figure 22. Exemplary farm layout. New measurement devices or structures are circled.

The assumed water measurement points are circled in Figure 22 for clarity. Some canals measure the water at farm turnouts. If that is the case, then one of the necessary flumes may be installed but may not be instrumented with SCADA and a water surface level sensor. Other flumes shown in Figure 21 conceptually are likely added, in order to satisfy the requirements of a change decree or operational reporting requirements of the State Engineer. This exemplary layout does not show a weather station. Every farm involved in a lease operation would not need a weather station. However, it is estimated that one weather station would be suitable to every 10,000 acres of farm fields involved in the System. The exact instrumentation requirements and layout must be done on a farm-by-farm basis.

5.6 System Implementation at the Ditch Company Level

The bigger System is best managed at the ditch company or farmer cooperative level for several reasons:

1) A larger block of CU water will be needed and a group of farms can together develop a suitable block (1,000 acre feet of CU water plus).

2) A long term water lease agreement is preferred between the ditch company as the actual water right holder and the municipal or environmental user as the water user. (See Appendix 2 for an example of such a water lease.)

3) System operations are likely best monitored at the canal level and the ditch company may be in the best position to provide this management.

The US Bureau of Reclamation has encouraged Bureau projects as well as other canal systems to implement SCADA. This recommendation is driven purely by canal operational reasons, whether it be simply monitoring water surface levels or moving toward gate actuation and automation. The USBR staff developed Figure 23 as a means of conveying ideas to canal operators. This figure exemplifies what SCADA hardware, software, and communication will possibly be available, in some instances, and additional instrumentation for the System needs could be added on top of an existing SCADA umbrella.

5.7 Issues and Pitfalls Associated with Concept Implementation

Clearly there are questions, risks, issues, and pitfalls associated with implementation of a System program such as is described. Considering comments from and meetings with potential first adopters, the primary issues are known to be:

- Can municipal interests view a long term lease as a viable part of their water portfolio and their safe yield?
- Can farmers accept the perceived dramatic changes to their operations?
- Can the science underpin the operational strategy sufficiently to satisfy objectors and the Water Court?
- Water diversion and delivery infrastructure is not necessarily in place so there is a question of how to physically transfer water - short of building new or adapted infrastructure.
- Whether or not there will be favorable farmer interest / acceptance of a lease or a lease buyout which would provide upfront money for on-farm improvements.

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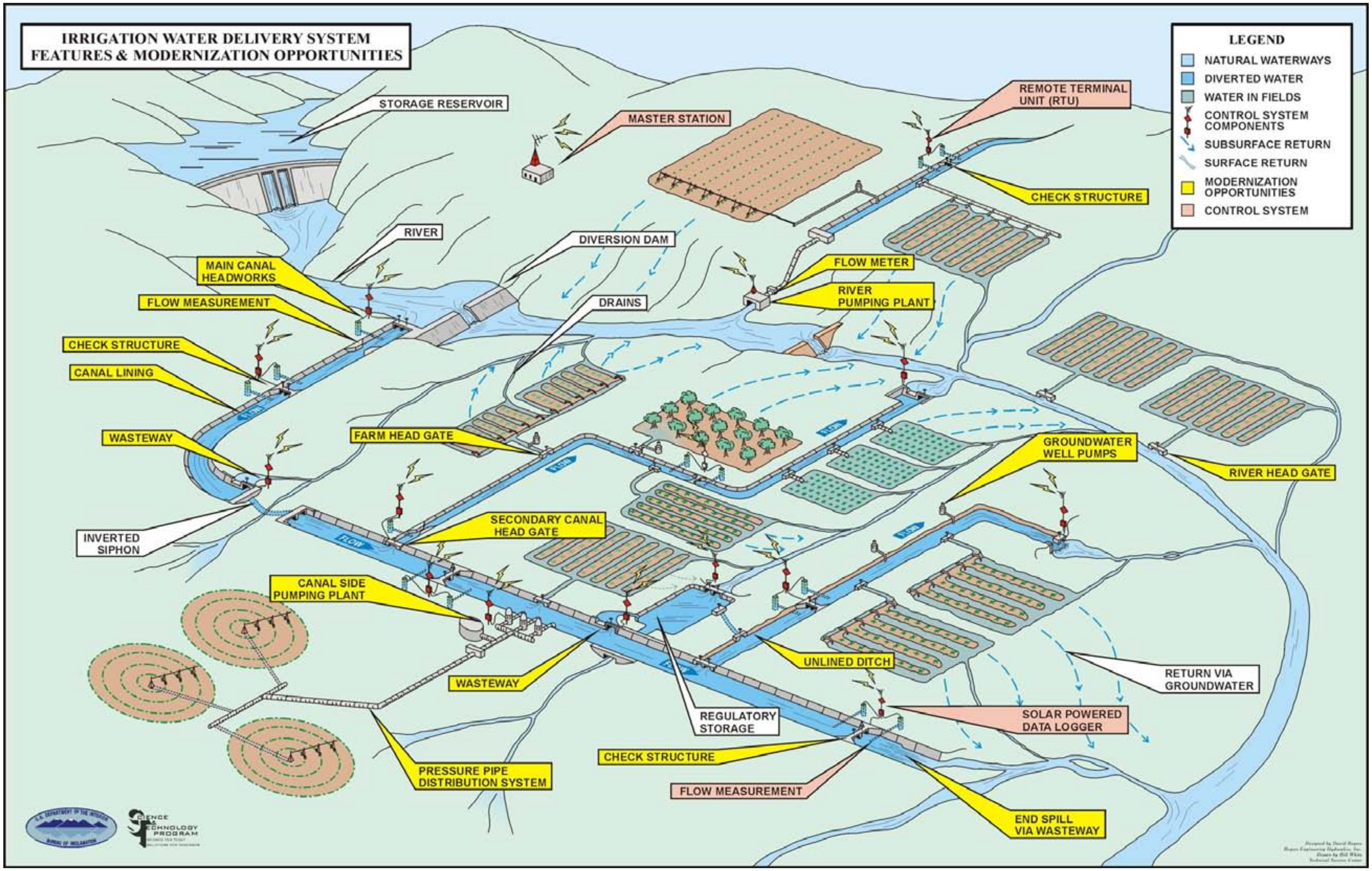

Figure 23. A depiction of a highly modernized canal system (courtesy of USBR).

CHAPTER 6
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The hypothesis of this dissertation is that an optimized package of irrigated farming practices based on a consumptive use (CU) water budget can demonstrate the feasibility and basic concept of selling or leasing a fraction of a water right to make farming more attractive, profitable, and sustainable.

Through an engineering study of crops, acreages, historic evapotranspiration, and water diversions, water rights in Colorado can be quantified for the historic consumptive use. Quantification is necessary if one is to change the water right from the decreed type of use, place of use, point of diversion, and season of use. The costly engineering and legal effort to change a water right (the transaction cost) is undertaken in order to bring greater value to the water right and increase the flexibility for future uses. Municipal, industrial, and environmental interests are actively searching for senior surface water rights, usually agricultural water rights that can be moved from agriculture to other purposes. This process of locating and moving a water right often results in farms being bought up and permanently dried up. This is a dynamic that is happening in the South Platte River Basin and believed to not be in the best interests of the larger community or in maintaining a sustainable irrigated agricultural system. Total water management is an admirable concept that can be furthered using the optimization Model and System as described. Use of this technology helps answer the question of how to bring more cooperation and flexibility between conflicting users, share valuable water resources, bring benefits to the community, and sustain a viable agricultural economy.

The Model, the simulation and optimization model described in this dissertation, is researched and developed to allow a farmer user to view the CU differently than in the past. Namely, the CU can be viewed as a farm water budget and evaluated for future uses. Might the farmer wish to part off a portion of the CU, under contract, to a higher economic value driven by non-agricultural interests? The optimization of future net returns, based on adoption of a package of changed farming practices, allows for a comparative analysis. Multiple runs of the Model can provide understanding of the potential and a sensitivity analysis based on changing inputs.

Multiple naïve scenarios with predictable outcomes were set up and run with The Model. The outcomes from running these naïve scenarios were valuable in identifying program elements and outputs that could be improved. Generally, the naïve scenarios verified the utility of the Model in helping a farmer-user 1) understand the approach and the process and 2) gain insights toward changed future practices that may be acceptable within their farming operations.

Farmers operating under a senior surface irrigation right within a ditch system may wish to work together as a new cooperative group or as a subset of ditch company shareholders wishing to implement this technology. This brings together and affords a larger block of CU water, and a larger block will be more attractive to the leasing entity. The ditch company or the new cooperative entity would become the managing entity. The resulting System would include SCADA hardware, software, and instrumentation suitable to farm management objectives, ditch company management objectives, and State Engineer operational reporting requirements.

Some farmers will not consider using this technology. Some farming operations are profitable, sustainable, and doing well in today's agricultural economy. Other farmers are operating in a marginal financial sense. An operational change using these technologies may increase net returns (profits), allow for, or support irrigation system improvements, and otherwise help those farmers stay in business and continue providing significant regional economic benefits.

6.1 Specific Recommendations

The following key recommendations are made as a result of completing this research, developing the Model described, and evaluating optimization scenario results:

1) Evaluate the Model in focus groups with both naïve users and farmer users or in additional one-on-one presentations to individual farmers.

2) Implement proof of concept projects in the near term. Validation of concepts could be on the basis of a study of ditch company interest in this approach and technology or as an actual implementation that could affect a water transfer between a water loaner and a water borrower.

3) Expand software and program development beyond the Model to include a robust database and tools for real time data acquisition and reporting.

4) Study specific instrumentation, communication methods, and SCADA RTU hardware that can affordably be utilized in the implementation and commissioning of this technology.

5) Evaluate the circumstances and potential for this technology in other regions and states operating under the prior appropriation system and experiencing agricultural to urban water transfers driven by regional population growth.

6) Add full featured risk analysis to the computational platform.

7) Expand crop production functions (database inputs) to other geographically diverse regions of other river basins.

8) With first adopter successes, consider expansion of the mathematical optimization aspects of the Model into a fully featured and robust expert system.

9) Add an output screen to the Model that focuses on the presumed farm water balance that would underpin an implementation of a preferred scenario.

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APPENDIX 1

MODEL INPUT VALUES
(DEFAULT VALUES BY CROP)

Default Values in the Model

Irrigated Corn - grain	Bu/ac
Yield	180
Seed	$90.00
Fertilizer	$155.00
Herbicide	$23.58
Crop Insurance	$41.35
Fuel	$15.00
Repair & Maintenance	$6.96
Labor	$7.81
Miscellaneous Pre-harvest Costs	
Total Preharvest	$339.70
Fuel	$5.34
Repair & Maintenance	$4.65
Labor	$1.54
Hauling	$33.49
Miscellaneous Harvest Costs	
Total Harvest	$45.02
Total Operating Costs	$384.72

Irrigated Winter Wheat	Bu/ac
Yield	70
Seed	$16.19
Fertilizer	$56.73
Herbicide	$29.63
Crop Insurance	$16.64
Fuel	$7.29
Repair & Maintenance	$4.64
Labor	$2.22
Miscellaneous Pre-harvest Costs	
Total Preharvest	$133.34
Fuel	$5.05
Repair & Maintenance	$2.90
Labor	$1.49
Hauling	$12.22
Miscellaneous Harvest Costs	
Total Harvest	$21.66
Total Operating Costs	$155.00

Irrigated Barley	Bu/ac
Yield	72
Seed	$16.19
Fertilizer	$56.73
Herbicide	$29.63
Crop Insurance	$16.64
Fuel	$7.29
Repair & Maintenance	$4.64
Labor	$2.22
Miscellaneous Pre-harvest Costs	
Total Preharvest	$133.34
Fuel	$5.05
Repair & Maintenance	$2.90
Labor	$1.49
Hauling	$12.22
Miscellaneous Harvest Costs	
Total Harvest	$21.66
Total Operating Costs	$155.00

Irrigated Corn - Silage	Tons/ac
Yield	18
Seed	$30.00
Fertilizer	$149.00
Herbicide	$82.00
Crop Insurance	$15.00
Fuel	$68.56
Repair & Maintenance	$10.04
Labor	$7.50
Miscellaneous Pre-harvest Costs	
Total Preharvest	$362.10
Fuel	$39.52
Repair & Maintenance	$13.13
Labor	$43.92
Hauling	$40.00
Miscellaneous Harvest Costs	
Total Harvest	$136.57
Total Operating Costs	$498.67

Irrigated Alfalfa	Tons/ac
Yield	6
Establishment Allocation (5 Years)	$41.47
Fertilizer	$222
Herbicide	$30.47
Insecticide	$33.00
Fuel	$68.56
Repair & Maintenance	$10.04
Labor	$7.50
Miscellaneous Pre-harvest Costs	
Total Preharvest	$412.68
Fuel	$4.20
Repair & Maintenance	$7.91
Labor	$3.91
Baling	$120.00
Hauling/ Stacking	$20.00
Miscellaneous Harvest Costs	
Total Harvest	$156.02
Total Operating Costs	$568.70

Irrigated Onions	cwt
	380
Seed	$182.00
Fertilizer	$280.00
Herbicide	$119.00
Crop Insurance	$143.00
Fuel	$150.00
Repair & Maintenance	$15.00
Labor	$240.00
Miscellaneous Pre-harvest Costs	$250.00
Total Preharvest	$1,379.00
Fuel	$30.00
Repair & Maintenance	$50.00
Labor	$200.00
Hauling	$20.00
Miscellaneous Harvest Costs	$1,300.00
Total Harvest	$1,600.00
Total Operating Costs	$2,979.00

Default Values in the Model (continued)

Irrigated Pinto Beans	CWT
Yield	45
Seed	$38.18
Fertilizer	$133.29
Herbicide	$33.10
Insecticide	$6.93
Fungicide	$20.52
Crop Insurance	$13.08
Fuel	$11.07
Repair & Maintenance	$4.91
Labor	$3.39
Miscellaneous Pre-harvest Costs	
Total Preharvest	$264.47
Fuel	$20.16
Repair & Maintenance	$7.78
Labor	$5.63
Hauling	$5.99
Miscellaneous Harvest Costs	
Total Harvest	$39.56
Total Operating Costs	$304.03

Irrigated Sugarbeets	CWT
Yield	0
Seed	$52.96
Fertilizer	$143.00
Herbicide	$108.57
Insecticide	$11.36
Fungicide	$19.75
Crop Insurance	$20.80
Hand Labor	$45.00
Fuel	$24.21
Repair & Maintenance	$11.42
Labor	$9.10
Miscellaneous Pre-harvest Costs	
Total Preharvest	$446.17
Fuel	$29.04
Repair & Maintenance	$54.00
Labor	$8.36
Hauling	$160.34
Miscellaneous Harvest Costs	
Total Harvest	$251.74
Total Operating Costs	$697.91

Irrigated Cabbage	50 lb box
Yield	650
Seed	$290.00
Fertilizer	$526.00
Herbicide	$30.00
Insecticide	$30.00
Fungicide	$260.00
Crop Insurance	
Fuel	$30.00
Repair & Maintenance	$10.00
Labor	$130.00
Miscellaneous Pre-harvest Costs	
Total Preharvest	$1,306.00
Boxes	$812.00
Fuel	$30.00
Repair & Maintenance	$45.00
Labor	$282.00
Hauling	$60.00
Miscellaneous Harvest Costs	
Total Harvest	$1,229.00
Total Operating Costs	$2,535.00

Irrigated Carrot	50 lb box
Yield	850
Seed	$172.00
Fertilizer	$95.00
Herbicide	$14.00
Insecticide	$50.00
Fungicide	
Crop Insurance	
Spike	$20.00
Fuel	$150.00
Repair & Maintenance	$32.00
Labor	$75.00
Miscellaneous Pre-harvest Costs	$300.00
Total Preharvest	$908.00
Boxes	
Fuel	$20.00
Repair & Maintenance	$25.00
Labor	$60.00
Haul, cool, pack	$3,000.00
Miscellaneous Harvest Costs	
Total Harvest	$3,105.00
Total Operating Costs	$4,013.00

Default Values in the Model (continued)

Dryland Corn	Bu/ac
Yield	57
Seed	$18.35
Fertilizer	$35.00
Herbicide	$30.00
Crop Insurance	$14.44
Fuel	$5.17
Repair & Maintenance	$2.56
Labor	$1.82
Miscellaneous Pre-harvest Costs	
Total Preharvest	$107.34
Fuel	$5.94
Repair & Maintenance	$4.77
Labor	$1.35
Hauling	$10.03
Miscellaneous Harvest Costs	
Total Harvest	$22.09
Total Operating Costs	$129.43

Dryland Winter Wheat	Bu/ac
Yield	0
Seed	$6.90
Fertilizer	$18.53
Herbicide	$9.27
Crop Insurance	$6.04
Fuel	$11.93
Repair & Maintenance	$8.43
Labor	$2.28
Miscellaneous Pre-harvest Costs	
Total Preharvest	$63.38
Fuel	$6.13
Repair & Maintenance	$2.97
Labor	$1.53
Hauling	$6.99
Miscellaneous Harvest Costs	
Total Harvest	$17.62
Total Operating Costs	$81.00

Dryland Alfalfa	Tons/ac
Yield	0
Establishment Allocation (5 Years)	$41.47
Fertilizer	$24.88
Herbicide	$4.17
Insecticide	$10.88
Fuel	$68.56
Repair & Maintenance	$10.04
Labor	$7.50
Miscellaneous Pre-harvest Costs	
Total Preharvest	$167.50
Fuel	$4.20
Repair & Maintenance	$7.91
Labor	$3.91
Baling	$120.00
Hauling/ Stacking	$20.00
Miscellaneous Harvest Costs	
Total Harvest	$156.02
Total Operating Costs	$323.52

Dryland Millet	CWT
Yield	25
Seed	$2.65
Fertilizer	$30.00
Herbicide	$11.44
Crop Insurance	$5.60
Fuel	$8.11
Repair & Maintenance	$4.48
Labor	$2.31
Miscellaneous Pre-harvest Costs	
Total Preharvest	$64.59
Fuel	$12.20
Repair & Maintenance	$7.19
Labor	$3.82
Hauling	$4.54
Miscellaneous Harvest Costs	
Total Harvest	$27.75
Total Operating Costs	$92.34

Dryland Sunflower	CWT
Yield	0
Seed	$16.94
Fertilizer	$51.90
Herbicide	$39.71
Insecticide	$9.59
Crop Insurance	$10.96
Fuel	$3.18
Repair & Maintenance	$1.89
Labor	$1.11
Miscellaneous Pre-harvest Costs	
Total Preharvest	$135.28
Fuel	$7.00
Repair & Maintenance	$4.62
Labor	$1.46
Hauling	$1.96
Miscellaneous Harvest Costs	
Total Harvest	$15.04
Total Operating Costs	$150.32

Dryland Canola	lb/ac
Yield	0
Seed	$18.00
Fertilizer	$33.73
Herbicide	$6.36
Insecticide	$0.00
Crop Insurance	
Fuel	$3.50
Repair & Maintenance	$3.00
Labor	$9.49
Miscellaneous Pre-harvest Costs	
Total Preharvest	$74.08
Fuel	$5.00
Repair & Maintenance	$15.00
Labor	$9.45
Hauling	$6.00
Miscellaneous Harvest Costs	
Total Harvest	$35.45
Total Operating Costs	$109.52

Dryland Barley	Tons/ac
Yield	30
Seed	$8.40
Fertilizer	$47.00
Herbicide	$46.84
Crop Insurance	$4.83
Fuel	$4.60
Repair & Maintenance	$6.39
Labor	$7.50
Miscellaneous Pre-harvest Costs	
Total Preharvest	$125.56
Fuel	$4.00
Repair & Maintenance	$6.39
Labor	$7.50
Hauling	$6.00
Miscellaneous Harvest Costs	
Total Harvest	$23.89
Total Operating Costs	$149.45

Dryland Sorghum	Tons/ac
Yield	0
Seed	$3.75
Fertilizer	$7.45
Fuel	$7.76
Repair & Maintenance	$2.83
Labor	$0.42
Miscellaneous Pre-harvest Costs	
Total Preharvest	$22.21
Fuel	$1.32
Repair & Maintenance	$2.57
Labor	$1.15
Hauling	$6.00
Miscellaneous Harvest Costs	
Total Harvest	$11.04
Total Operating Costs	$33.25

Default Values in the Model (continued)

Irrigated Crops	Price $$	FI Yield	Dryland Yield for DI	Units	Irrigation Requirement feet/acre	Fixed Costs $$/unit	Variable Costs $$/unit
Corn (grain)	4.25	180	55	bu	1.53	1.87	0.25
Wheat	5.25	90	35	bu	0.86	1.90	0.31
Barley	3.86	90	35	bu	0.86	1.90	0.31
Pinto Beans	24.00	17	5	cwt	1.20	5.87	0.88
Sugar Beets 1,2	47.80	32	12	tons	1.86	13.94	7.86
Corn (silage)	20.00	26	----	tons	1.53	20.00	7.59
Alfalfa	125.00	6	3	tons	1.93	68.00	26.00

Dryland Crops	Price	FI Yield	Dryland Yield	Units	Irrigation Requirement	Fixed Costs $$/unit	Variable Costs $$/unit
Corn	4.25	180	55	bu	none	1.88	0.39
Wheat	5.25	90	35	bu	none	1.80	0.50
Barley	3.86	90	35	bu	none	3.57	0.68
Sunflower	18.00	20	12	cwt	none	12.00	1.36
Sorghum	7.26	70	35	bu	none	0.31	0.16
Proso Millet	80.00	60	30	cwt	none	2.6	3.68
Canola	17.40	30	15	cwt	none	2.00	0.97

Data sources:

1. Sugar beet yield http://www.ers.usda.gov/Briefing/Sugar/Data.htm Table 14
2. Sugar beet prices http://www.ers.usda.gov/Briefing/Sugar/Data.htm Table 12
3. Barley prices: http://www.nass.usda.gov/Statistics_by_State/Montana/Publications/economic/prices/barleypr.htm
4. Corn silage price http://hayandforage.com/mag/corn_silage_worth/
5. Corn silage yield: http://www.pioneer.com/web/site/portal/menuitem.7d750b63e7394ade3c3d48e7d10093a0/
6. Canola yields: http://www.ers.usda.gov/Briefing/SoybeansOilcrops/Canola.htm#canolaprod Table 24
7. Sorghum yield: http://www.nass.usda.gov/Newsroom/2010/01_12_2010.asp
8. Canola, dry beans, alfalfa, barley, corn, wheat, sorghum, sunflower, prices: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1002
9. Bean, sunflower, alfalfa yields – Mr. Daniel Palic – conservation officer, NRCS, Julesburg, CO – personal conversation by Dale Dunn.

Average farm size in Weld County = 193 acres: NASS statistics 2007 Colorado

APPENDIX 2

EXAMPLE LEASE AGREEMENT

(Insert PDF file here, appended to PDF document)

AGREEMENT FOR LEASE OF WATER PRODUCED BY HIGH LINE CANAL COMPANY STOCK

This agreement for lease of water produced by High Line Canal Company stock ("Lease") is entered into and effective upon the date set forth herein below on the Lessor Execution Page. This Lease is made by and between the undersigned shareholder of stock of the High Line Canal Company ("Lessor"), and the City of Aurora, Colorado, a Colorado municipal corporation of the counties of Adams, Arapahoe, and Douglas, acting by and through its Utility Enterprise ("Aurora").

WITNESSETH:

Whereas, Lessor represents he owns the number of shares of stock listed on Lessors Execution Page in the High Line Canal Company ("Subject Stock") and that such shares are in good standing with said Ditch company with all assessments current and paid; and

Whereas, the water derived from the Subject Stock is used to irrigate that certain real property further described on the Seller's Execution Page, ("Historic Irrigated Land"); and,

Whereas, the High Line Canal Company has the following water rights:

District	Priority Number	Priority Date	Adjudication Date	Amount in CFS
14	4	12/31/1861	03/23/1896	40.0
14	25	07/01/1869	03/23/1896	16.0
17	3	03/07/1884	04/08/1905	32.5
14	48	06/30/1885	03/23/1896	30.0
14	50	03/11/1886	03/23/1896	2.0
14	60	01/06/1890	03/23/1896	378.0
14	61	12/13/1890	03/23/1896	2.5

as well as rights to Winter Storage Water pursuant to the Decree entered in Water Division 2, Case No 84CW179; and,

Whereas, Aurora is a municipal corporation of the State of Colorado, acting by and through its Utility Enterprise, and as such has the need for the water represented by the water rights derived from the Subject Stock for the purposes of supplying water for municipal and other uses for the inhabitants of Aurora and to those persons, firms, or corporations deriving water from the said Aurora Utility Enterprise water system; and

Whereas, the parties hereto acknowledge that the year 2002 marked the fourth consecutive year of below average precipitation in Colorado and that the associated low amounts of precipitation have created extreme drought conditions across most of the State, including Aurora; and

Whereas, the extreme drought conditions have forced Aurora to enter into short term supply agreements like this Lease to preserve the health and safety of its community; and

Whereas, the Lessor is aware of the extreme drought conditions and is willing to lease said water to Aurora to assist Aurora during the term of this Lease.

NOW, THEREFORE, in consideration of the foregoing recitals and in consideration of the promises, agreements and payments herein after set forth, the adequacy and sufficiency of which are hereby acknowledged, the Parties agree as follows:

1. **Lease** Pursuant to the terms hereof, the Lessor hereby leases to Aurora the water derived from the Subject Stock. If for any reason the Lessor is unable to deliver all the water derived from the Subject Stock at the headworks of the High Line Canal, Aurora's Annual Payment as described hereinafter will be proportionally reduced (for example, if assessments have not been paid to the High Line Canal Company).

2. **Term** Unless terminated as set forth herein below, this Lease shall have an initial term of the remainder of the year of 2003, the entire year of 2004, and during 2005 through November 14, 2005. The term of this Lease will begin upon the commencement of diversions by Aurora for its use of the water from the Subject Stock following Aurora's receipt of the approval described in Paragraph 3 hereinbelow. For the year 2003 the Lessor will have the discretion to either begin this Lease at that point in 2003 or wait until the beginning of 2004. Should Aurora not obtain the referenced approvals for diversion during 2003, this Lease may begin in 2004. If either Aurora or the Lessor gives notice to the other party no later than February 1, 2005, this Lease may be terminated for the year 2005. Such termination for the year 2005 may occur for any reason. Upon any termination of this Lease for 2005, Aurora will not be entitled to any of the winter water from the 2004-2005 Winter Water Program attributable to the Subject Stock. This Lease will ultimately end no later than November 14, 2005 unless sooner terminated pursuant to the terms hereof.

3. **Ability for Aurora to Use Water** Aurora agrees to promptly investigate and request the administrative approvals of necessary vehicles/mechanisms to allow the temporary use by Aurora and the transportation to Aurora of the water produced by the Subject Stock within Aurora's municipal boundaries for Aurora's municipal and other purposes. Should Aurora determine in its sole good faith discretion that such administrative approvals of the vehicles/mechanisms to allow the temporary use and transportation are not available, Aurora will promptly notify the Lessor and this Lease will terminate upon such notification. Upon such termination, neither party will have further duty owing to the

other. In the event of such termination the Lessor will retain the minimum payment discussed hereinafter. Should Aurora be successful in obtaining administrative approvals of the vehicles/mechanisms to allow the contemplated temporary use and transportation, the terms of this Lease will become effective.

4. **Designating Shares to be Leased**

   a. **Limitation on Shares** Aurora may limit the total number of High Line Canal Company shares it will lease. Should the number of High Line Canal Company shares available for lease to Aurora be larger than the number of shares Aurora desires to lease, Aurora will have 30 days to reduce in the number of shares that are the subject of this Lease. The Lessor may then either terminate this Lease or continue with the Lease at the reduced number of shares. Upon such termination, neither party will have further duty owing to the other. Aurora will indicate the total number of shares that will be leased on its signature page of this Lease. The Lessor will indicate his acceptance of the total by his initials on the Aurora signature page. Provided this Lease is not terminated, the number of shares listed on Aurora's signature page will control over the number of shares listed on the Lessor Execution Page.

   b. **Lateral Shareholders** Aurora agrees that in accordance with Canal Company requirements, it will not lease High Line Canal Company shares from shareholders on a communal lateral without either the approval of all members of that communal lateral or that all members of such communal lateral also lease their shares to Aurora.

5. **Payments**

   a. **Minimum Payment** Upon the execution of this Lease by the Lessor, Aurora will pay the Lessor a one time non-refundable "Minimum Payment" of $100.00 per share of Highline Canal Company that is described in this Lease. A share of High Line Canal Company generally produces the amount of water necessary for irrigation of and is associated with Ten (10) acres of land under this ditch. The number of shares of Highline Canal Company water and the number of acres of Historic Irrigated Land that are the subject of this Lease are set forth on the Lessor's Execution Page. This Minimum Payment, although non-refundable, shall be fully credited toward any first payment made pursuant to Paragraph 5 b hereinbelow during the year 2003. This Minimum Payment will not be credited toward any sums due in either 2004 or 2005.

b. **Lease Price** Prorated as set forth below for the year 2003, the "Lease Price" that Aurora will pay on an annual basis is $5,280.00 per share. A share of High Line Canal Company generally produces the amount of water necessary for irrigation of and is associated with approximately ten acres of land under this ditch. The first payment will be made within sixty days from the date Aurora receives the administrative approvals of the vehicles/mechanisms for its temporary use and transportation of the water produced by the Subject Stock. The first payment will be either $5,280.00, or the prorated amount as may be applicable in the year 2003, less $500.00 per share and less credit for the Minimum Payment. During the years 2004 and 2005, if applicable, the first payment will be made by March 15. (For example, if no proration applies the first payment would be $4,780.00.) The second payment will be $500.00 per share and will be due October 15 of the subject year. As further discussed below, the withholding of funds for making the second payment is to ensure the Lessor will undertake proper weed control and land stabilization measures during the growing season. Should Aurora incur any expenses for weed control and land stabilization measures related to the Historic Irrigated Land because the Lessor did not adequately perform those activities, Aurora's costs will be deducted from the second payment and retained by Aurora. The Lessor shall not have any further liability for any Aurora expenses for weed control and land stabilization measures on the Historic Irrigated Land other than the up to $500.00 per share to be withheld.

c. **Pro Ration** The following pro ration table will apply for the year 2003 concerning this Lease. First payments in the pro-rated table below will be subject to credit for the $100.00 per share Minimum Payments. If the initial day of diversion by Aurora pursuant to this Lease occurs after the first day of the subject months of April – July, then the Annual Payment will be prorated for the remainder of the month in which diversions begin.

Commence on or Before	Annual payment for 2003	Weed Control/Land Stabilization Withholding from Second Payment	Pro-Rate First Payment
July 1	$3,160	$500	$2,660
August 1	$1,850		$1,850

d. **No Further Payments During 2003 Without Approvals** No payment other than the Minimum payment will be made if the administrative approvals of the vehicles/mechanisms to allow Aurora's temporary use and transportation of the water produced by the Subject Stock does not occur so as to allow commencement of the Lease on or before August 1, 2003.

e. **Loss of Production Payment** The parties recognize that the Historic Irrigated Land that is idle for an extended period may experience a reduction in productivity when farming is re-commenced. To provide full compensation for any such reduction, the Parties agree Aurora will pay to the Lessor, $1,000.00 per share for each year that the Historic Irrigated Land is out of production pursuant to this lease, not to exceed $2,000 per share. A partial year in 2003 will count as a full year. This payment will be made in two equal portions, with the first payment occurring on May 1 of the first year following resumption of irrigation and farming activities on the land after the termination of this Lease, and the second payment occurring on May 1 of the second year following resumption of irrigation and farming activities.

f. **Ditch Company Assessments** Aurora agrees to pay to the Lessor $100.00 per share for High Line Canal Company stock assessments upon the Subject Stock during each year of this Lease. This payment will be made at the same time during each year of this Lease as the first payments made pursuant to Paragraph 5 b hereinabove. The Lessor shall be responsible for any additional assessment costs that may be due the High Line Canal Company. If the Lessor is or becomes in arrears regarding his High Line Canal Company assessments, Aurora at its sole discretion may pay such arrearage to the High Line Canal Company and deduct an equal amount from subsequent payments due the Lessor.

g. **Winter Water Storage Cost Payment** Aurora will make payment to the High Line Canal Company an amount equal to the storage costs for the number of shares of the Subject Stock leased to Aurora pursuant to this Lease. Any 2003 payment will be made 30 days after Aurora receives the approval described in Paragraph 3 hereinabove. Any subsequent payments will be made annually on April 15 during the term of this Lease. For the year 2003, this payment will be made on the percentage of winter water available to the City from the total winter water available to the High Line Canal Company stockholders from the 2002-2003 program.

h. **No Responsibility to Tenant Farmers** All Payments from Aurora pursuant to this Lease shall be made to the Lessor, or his assignee as he may direct in writing. Aurora will have no responsibility for any payments whatsoever to any tenant farmer who may have an agreement with the Lessor.

6. **Ditch Company Approval and Amendments** The Parties agree it will be the responsibility of the Lessor to act in concert with other lessors to obtain any and all changes and amendments Aurora reasonably believes are necessary in the High Line Canal Company Articles of Incorporation and By-Laws to allow for the temporary use of water by Aurora as contemplated by this Lease. In addition to changes or amendments of the Articles and the By-Laws, the Lessor will also have sole responsibility to within Thirty (30) days following Aurora's delivery to the High Line Canal Company of its engineering report concerning the use of the water derived from the Subject Stock to obtain any approval or authorization required by the High Line Canal Company to allow for Aurora's temporary water produced by the Subject Stock pursuant to this Lease.

7. **Dry up of Historic Irrigated Land Associated with Subject Stock** A fundamental requirement for this Lease of the Subject Stock is the non-use of water upon and the non-production of the Historic Irrigated Land ("Dry-up") during the term hereof. For each of the shares of the Subject Stock leased by Aurora, the Lessor will Dry-up and withhold from production approximately 10 acres of the Historic Irrigated Land. These provisions will become effective upon Aurora' notification to the Lessor that it has received the approval required in Paragraph 3 hereinabove. Historic Irrigated Land that is the subject of these provisions will be identified on maps provided to the State and/or Division Two Engineer Office(s) and the High Line Canal Company. The subject Historic Irrigated Land will be monitored to insure no irrigation thereof during the term of this Lease.

8. **Weed Control and Land Stabilization** The Parties agree that weed control and stabilization of the Historic Irrigated Land taken out of production during the Lease period is very important. The Lessor, at his sole cost, agrees to undertake operations to mitigate the blowing of dust and other erosion and the control of weed growth on Historic Irrigated Land. Specific operations will be determined in good faith consultation with High Line Canal Company in accordance with terms and conditions in the approval to use the Subject Stock from the State Engineer, and adjusted for individual circumstances as appropriate. Anticipated operations may include the following:

   Alfalfa Fields

   These fields will continue in an as is state. Harvesting or grazing during the term of this Lease may be allowed at Aurora's sole discretion in accordance with terms and conditions in the approval to use the Subject Stock from the State Engineer. If these fields require monitoring to determine depth to water table, any installation of monitoring wells will be at Aurora's expense. The Parties will determine the location of any such monitoring wells cooperatively.

The State Engineer may impose special rules regarding the dry-up of alfalfa fields. Should the water table be high enough that sub-irrigation of the alfalfa causes Aurora to lose some yield from a particular field, activities to kill the alfalfa in such field will be undertaken or the field will be removed from the leased share calculation.

Stubble Fields

Fields containing stubble from the previous years crop will be left as is to provide protection from wind. If existing stubble is not deemed adequate, in Aurora's discretion, additional measures may be required. Such measures may include planting of a cover crop such as spring wheat and an irrigation of the crop, and mechanical operations on the field such as furrowing or chiseling. Irrigation associated with the establishment of a cover crop will use water attributable to the Subject Stock being leased by Aurora. Harvesting or grazing during the term of this Lease may be allowed at Aurora's sole discretion in accordance with terms and conditions in the approval to use the Subject Stock from the State Engineer.

Open Fields

Open fields will require measures to control the blowing of dust. The measures may include furrowing or chiseling the fields, planting a cover crop such as spring wheat and some irrigation of the crop, or other measures the Parties may agree are appropriate. Irrigation associated with the establishment of a cover crop will use water attributable to the Subject Stock being leased by Aurora. Harvesting or grazing during the term of this Lease may be allowed at Aurora's sole discretion in accordance with terms and conditions in the approval to use the Subject Stock from the State Engineer.

Weed Control

Measures will be undertaken by the Lessor to control the weeds on the Historic Irrigated Lands. These measures may include the mowing of weeds or application of herbicide. Other measures, including grazing, may be undertaken at Aurora's discretion.

9. Aurora May Assume Weed Control and Land Stabilization Activities

The parties agree that the Historic Irrigated Land must be stabilized during the term of this Lease such that noxious weeds do not proliferate and blowing dust and other erosion does not occur. Lessor acknowledges that he has primary responsibility to accomplish the stabilization and control. Nevertheless, if the stabilization and control does not occur, Aurora may take steps to provide appropriate land stabilization and weed control, as it deems necessary in its good faith discretion. The Lessor hereby grants Aurora permission to enter upon the Historic Irrigated Land and undertake whatever stabilization and control measures, as Aurora deems necessary. As set forth above, expenses related to this operation may be deducted from the subsequent payments. However, the Lessor shall not have any further liability for any Aurora expenses for weed control and land stabilization measures on the Historic Irrigated Land other than the up to $500.00 per share to be withheld.

10. **<u>Taxes</u>** The Lessor shall have sole responsibility for any taxes, property or otherwise, related to the Historic Irrigated Land or the Subject Stock. The parties acknowledge that it is anticipated that such Historic Irrigated Land will be considered irrigated farmland notwithstanding the cessation of irrigation during the period of this Lease.

11. **<u>Water Included</u>** The water available to Aurora pursuant to this Lease shall be all native water available to the Lessor, as a result of his ownership of the Subject Stock, which will include water derived from the Winter Water Storage Program. Aurora will not be entitled to any water derived from High Line Canal Company wells. Nothing herein shall prevent the High Line Canal Company from diverting any rights not allowed to be used by Aurora and applying the same to land not required to be taken out of production pursuant to the terms hereof.

12. **<u>Engineering and Legal Activities by Aurora</u>** The Parties agree that it will be Aurora's sole responsibility to complete any legal and engineering activities necessary to allow for the temporary use of the water derived from the Subject Stock by Aurora pursuant to this Lease. Nevertheless, the Lessor shall cooperate with Aurora in supplying data and information as needed by Aurora to complete these activities. Aurora agrees that it will supply all engineering and hydrologic materials it develops to the High Line Canal Company for that Company's critique. Any agreements necessary for Aurora to obtain the High Line Canal Company's critique will be separate agreements between Aurora and the High Line Canal Company.

13. **<u>Non-Business Days</u>**. If any date for any action under this Lease falls on a Saturday, Sunday, or a day that is a "holiday" as such term is defined in Rule 6. of the Colorado Rules of Civil Procedure, then the relevant date shall be extended automatically until the next business day.

14. **<u>Entire Agreement of the Parties</u>**. This writing constitutes the entire agreement between the parties regarding Lease of water produced by the

Subject Stock and supersedes all prior written or oral agreements, leases, negotiations, representations, and understandings of the parties with respect to the subject matter contained herein. Neither party has relied upon any fact or representation not expressly set forth herein.

15. **Amendment** This Lease may be amended, modified, changed, or terminated in whole or in part only by a written document duly authorized and executed by the parties hereto.

16. **Venue** Venue for the trial of any action arising out of any dispute hereunder shall be in the District Court in and for the County of Otero, Colorado.

17. **Governing Law** This Lease and its application shall be construed in accordance with the laws of the State of Colorado.

18. **Intent of Lease** This Lease is intended to describe the rights and responsibilities of and between the named parties and is not intended to, and shall not be deemed to confer rights upon any persons or entities not named as parties, nor to limit in any way the powers and responsibilities of Lessor, Aurora, or any other entity not a party hereto.

19. **No Construction Against Drafter** This Lease was drafted by Aurora with review and comment from the attorney for the High Line Canal Company. The Lessor is encouraged by Aurora to review this Lease with his own legal counsel prior to executing this Lease. Accordingly, the Parties agree the legal doctrine of construction against the drafter will not be applied should any dispute arise concerning this Lease.

20. **Non-Severability** Each paragraph of this Lease is intertwined with the others and is not severable unless by mutual consent of Lessor and Aurora.

21. **Effect of Invalidity** If any portion of this Lease is held invalid or unenforceable for any reason by a court of competent jurisdiction as to either party or as to both parties, the parties will immediately negotiate valid alternative portion(s) that as near as possible give effect to any stricken portion(s).

22. **Non-Assignability** Neither party may assign its rights or delegate its duties hereunder without the prior written consent of the other.

23. **Successors and Assigns** This Lease and the rights and obligations created hereby shall be binding upon and inure to the benefit of the parties hereto and their respective heirs, successors and assigns in the event assignment is allowed.

24. **Waiver of Breach** Waiver of breach of any of the provisions of this Lease by either party shall not constitute a continuing waiver of any

subsequent breach by said party of either the same or any other provision of this Lease.

25. **Multiple Originals** This Lease may be simultaneously executed in any number of counterparts, each one of which shall be deemed an original, but all of which constitute one and the same Lease.

26. **Headings for Convenience** Headings and titles contained herein are intended for the convenience and reference of the parties only and are not intended to define, limit, or describe the scope of intent of any provision of this Lease.

27. **Recordation** Following the execution of this Lease, Aurora may cause this Lease to be recorded with the Clerk and Recorder's Office of Otero County or Pueblo County, Colorado, as it may desire. Upon termination of this Lease, Aurora shall execute and record such additional documents as Lessor reasonably may require to provide notice of termination.

28. **Survival of Representations** Each and every covenant, promise, and payment contained in this Lease shall not merge in any deed, assignment, covenant, escrow agreement, easement, lease or any other document, but shall survive each nevertheless, and be binding and obligatory upon each of the parties hereto.

29. **Definitions and Interpretations** Except as otherwise provided herein, nouns, pronouns and variations thereof shall be deemed to refer to the singular or plural, and masculine or feminine, as the context may require. Any reference to a policy, procedure, law, regulation, rule or document shall mean such policy, procedure, law, regulation, rule or document as it may be amended from time to time.

30. **Sole Obligation of Utility Enterprise** The parties agree any and all obligations of Aurora under this Lease are special and limited obligations payable solely out of and secured by an irrevocable (but not necessarily exclusive) subordinate pledge of the net revenues, after payment of all costs of operation and maintenance, of the municipal water system of the City of Aurora operated by the Utility Enterprise. Lessor further agrees the obligations of Aurora do not constitute a debt or indebtedness or a multiple-fiscal year debt or other financial obligation of the City of Aurora within the meaning of any constitutional, charter or statutory provision or limitation. Lessor further agrees the obligations of Aurora are not payable in whole or in part from the proceeds of general property taxes or any other form of taxation, and the full faith and credit of the City of Aurora is not pledged for the payment of the obligations of Aurora pursuant to this Lease. Lessor further agrees any lien and pledge of the net revenues securing payment of the obligations of Aurora are expressly subordinate to

all other than current obligations payable from the revenues of the water system of the City of Aurora operated by the Utility Enterprise.

31. **Carriage Water** Pursuant to Article IV of the Bylaws of the High Line Canal Company, Lessor shall request the approval of this Lease by the Board of Directors of the High Line Canal Company. The parties to this Lease understand that the Board may require terms and conditions to prevent injury to non-leasing shareholders, including but without limitation consideration of evaporation and seepage losses and operating conditions, so that non-leasing shareholders and shareholders leasing less than all of their shares will receive as much water, and in just as convenient a manner, as if the Lease did not exist. It shall be Aurora's obligation, without reduction in payments under this Lease, to leave such reasonable portion of the leased water in the canals or other structures of the High Line Canal Company as the Board of Directors shall in good faith by using commonly accepted engineering methods, determine is necessary to prevent injury to non-leasing stockholders. The High Line Canal Company is an intended beneficiary of this paragraph and may enforce the same.

32. **Aurora Responsibility** Once the delivery to Aurora of any water leased hereunder has been completed, Aurora shall assume sole liability for any loss, damage, or injury that may occur to persons or property as the direct or indirect result of its control and/or use of such water.

33. **Aurora Representation** Aurora is authorized under the Constitution and laws of the State of Colorado to enter into this Lease and to perform all of its obligations hereunder.

34. **Uniform Agreement** Except for the number of shares of Subject Stock and the description of the Historic Irrigated Land, the parties agree the form of this Lease will be uniform and identical with the terms between Aurora and all leasing Lessors.

CITY OF AURORA, COLORADO,
Acting By and Through Its Utility Enterprise

NUMBER OF SHARES 2.1

Lessor's Initials JDC X

By: ______________________________
Paul E. Tauer, Mayor

ATTEST:

____
Debra A. Johnson, City Clerk

APPROVED AS TO FORM FOR AURORA

____
John M. Dingess, Special Counsel

State of Colorado)
) ss.
County of Arapahoe)

The forgoing Lease was acknowledged before me this ______ day of ___________, 2003 by Paul E. Tauer, Mayor and attested to by Debra A Johnson, City Clerk of the City of Aurora, a Colorado Municipal Corporation of the Counties, Adams, Arapahoe and Douglas, acting by and through its Utility Enterprise.

Witness my hand and official seal

My Commission Expires: _________________

____
Notary Public

SEAL

Lessor Execution Page

Lessor should seek review of this Lease by his own attorney prior to execution.

LESSOR [signature] DATE: ________

NUMBER OF SHARES: 5.0

State of COLORADO)
) ss.
County of OTERO)

The foregoing Lease was acknowledged before me this 7TH day of APRIL, 2003, by James Colvin Lessor.

Witness my hand and official seal

My Commission Expires: 8/10/06

[signature]
Notary Public

SEAL

Historic Irrigated Land
(Number of Acres and Description)

As per attached map

APPENDIX 3

APPLICABLE COLORADO STATUTES

Colorado Statute

37-92-308. Substitute water supply plans - special procedures for review - water adjudication cash fund - legislative declaration - repeal.

(1) The general assembly hereby finds, determines, and declares that:

(a) There are certain circumstances under which the time required to go through the water court adjudication process can be problematic for some water users. Prior to January 1, 2002, substitute water supply plans had come into common usage for a number of water users, and based on this precedent, it appears desirable to establish some additional authority for the state engineer to approve substitute water supply plans.

(b) Prior to January 1, 2002, the general assembly gave the state engineer certain authority to approve exchanges and substitute water supply plans, including substitute water supply plans involving sand and gravel mines approved pursuant to sections 37-90-137 (11) and 37-80-120 (5); exchanges pursuant to sections 37-80-120, 37-83-104, and 37-83-106, and other statutes authorizing exchanges; and water uses that are part of the Arkansas river water bank pilot program approved pursuant to article 80.5 of this title; and this section shall not apply to such plans and exchanges.

(c) (I) Prior to January 1, 2003, the general assembly gave the state engineer administrative authority to regulate wells upon promulgation of rules for a river basin or aquifer, subject to the review of the water judge as provided in section 37-92-501 (3). The general assembly hereby ratifies the amended rules governing the diversion and use of tributary ground water in the Arkansas river basin of Colorado, as approved by the water judge for water division 2, that became effective on June 1, 1996.

(II) On and after January 1, 2003, the state engineer shall have the authority in water division 2 to promulgate and amend well administration rules pursuant to sections 37-80-104 and 37-92-501 that include the authority to approve replacement plans that allow the continuing operation of wells causing out-of-priority depletions without requiring a plan for augmentation approved by the water judge.

(III) On and after January 1, 2003, the state engineer shall not have any authority in water division 1 to approve plans for, or to otherwise allow, the operation of wells, including augmentation wells, that cause out-of-priority depletions unless the wells are operated in accordance with plans for augmentation approved by the water judge or as allowed in this section.

(2) In addition to the authority previously granted to the state engineer, listed in subsection (1) of this section, the state engineer is authorized to review and approve substitute water supply plans only under the circumstances and

pursuant to the procedures set forth in this section.

(3) (a) To provide sufficient time to fully integrate certain wells into the water court adjudication process for augmentation plans, during 2003, 2004, and 2005, the state engineer may approve annual substitute water supply plans for wells operating in the South Platte river basin that have been operating pursuant to substitute water supply plans approved before 2003, or for augmentation wells, using the procedures and standards set forth in this subsection (3). After December 31, 2005, all such wells shall comply with the provisions of subsection (4) of this section in order to continue operation under a substitute water supply plan. The general assembly finds that this three-year period is a sufficient amount of time to develop augmentation plan applications for these wells, and there shall be no subsequent extensions of this deadline. Beginning January 1, 2006, ground water diversions from all such wells shall be continuously curtailed unless the wells are included in a plan for augmentation approved by the water judge for water division 1, are included in a substitute water supply plan approved pursuant to subsection (4) of this section, or can be operated under their own priorities without augmentation.
(b) Beginning January 1, 2003, the state engineer may approve the operation of a well described in paragraph (a) of this subsection (3) under a substitute water supply plan if the following conditions are met:

(I) The well is tributary to the South Platte river, has been included in a substitute water supply plan previously approved by the state engineer or is an augmentation well, and is included in a new written request for approval of a substitute water supply plan filed with the state engineer after January 1 of each calendar year from 2003 to 2005. The written request shall be signed by a person with legal authority to represent all of the owners of the wells subject to the request and shall contain acknowledgments that the operation of all wells in the substitute water supply plan pursuant to this subsection (3) shall cease no later than December 31, 2005, and that the wells shall be included in an application for approval of a plan for augmentation filed in the district court for water division 1 no later than December 31, 2005, in order to continue subsequent pumping, unless the wells can be operated under their own priorities without augmentation. The request shall also identify for each well, including any augmentation wells: The permit number and location; the projected use and volume of pumping; for all wells using the modified Blaney-Criddle method to determine consumptive use, the projected number of acres and crops to be irrigated; the anticipated stream depletions that affect the river after October 31, 2002, until eighteen months after the date of the request in time, location, and amount, including a detailed description of how such depletions were calculated, and shall list the identity, priority, location, and amount of all replacement water sources to be used to replace stream depletions, including both accretions and depletions attributable to any augmentation wells. Upon the request of any party who has subscribed to the substitute water supply plan notification list for water division 1, the applicant for a substitute water supply plan shall also provide the model used to calculate stream depletions and the assumptions, input data, and output data used by the applicant in such model.

(II) The applicant has provided written notice of the request for approval of the substitute water supply plan by first-class mail or electronic mail to all parties who have subscribed to the substitute water supply plan notification list for water division 1, and proof of such notice is filed with the state engineer. The applicant shall also provide a complete copy of the request and all accompanying information by e-mail to all parties that have provided e-mail addresses for said notification list.

(III) The state engineer has given the owners of water rights and decreed conditional water rights thirty days after the date of mailing of such notice to file comments on the substitute water supply plan. Such comments shall include any claim of injury, any terms and conditions that should be imposed upon the plan to prevent injury to a party's water rights or decreed conditional water rights, and any other information the opposer wishes the state engineer to consider in reviewing the substitute water supply plan request.

(IV) The state engineer, after consideration of the comments, has determined that the operation and administration of such plan will replace all out-of-priority stream depletions in time, location, and amount in a manner that will prevent injury to other water rights and decreed conditional water rights, including water quality and continuity to meet the requirements of use to which the senior appropriation has normally been put pursuant to section 37-80-120 (3), and will not impair compliance with the South Platte river compact. The state engineer shall impose such terms and conditions as are necessary to ensure that these standards are met. In making the determinations specified in this subparagraph (IV), the state engineer shall hold a public hearing to address the issues. The public hearing shall be held no sooner than thirty-five days and no later than fifty days after the date of mailing of notice of the request for approval of the substitute water supply plan. Notice of the time and place of the hearing shall be provided no later than twenty days prior to the hearing to all parties who have subscribed to the substitute water supply plan notification list for water division 1. At the hearing, every party shall be allotted a reasonable amount of time by the state engineer to present its case or defense by oral and documentary evidence and to conduct cross examination. At its own expense, any party may cause the hearing to be recorded by a court reporter or by an electronic recording device. Additionally, in making the determinations specified in this subparagraph (IV), the state engineer shall use the standards listed in paragraph (c) of this subsection (3) for evaluating such plans. It is the legislative intent that the adoption of these standards is only an interim compromise, to give greater certainty to senior surface water users in Colorado than past practices of the state engineer have given, until augmentation plans for these wells have been approved by the water judge for water division 1 and final determinations about the methodologies for calculating the amount and timing of stream depletions have been made by the water judge. These interim standards shall not create any presumptions, shift the burden of proof, or serve as a defense in any application for approval of a plan for augmentation.

(c) (I) For those irrigation wells where diversions are actually measured using water meters or verified power conversion measurements, the presumed amount of consumptive use from wells used for flood irrigation shall not be less than fifty percent of diversions, and the presumed amount of consumptive use from wells used for sprinkler irrigation shall not be less than seventy-five percent of diversions. For those irrigation wells where diversions are not actually measured, the state engineer shall determine the amount of stream depletions using actual data for the crops grown, acres irrigated, surface water deliveries, and the modified Blaney-Criddle method.

(II) The state engineer shall determine the timing of all stream depletions caused by pumping wells included in the plan using the United States geological survey stream depletion factor method for all areas covered by such factors. In other areas, the state engineer shall use appropriate ground water models or other methods acceptable to the state engineer, based on the location of the well, the rate of pumping, the use being made of the ground water, and the aquifer characteristics.

(III) A substitute water supply plan approved pursuant to this subsection (3) shall require replacement of the following out-of-priority stream depletions that result from the pumping of wells in the plan: Out-of-priority stream depletions that affect the river after October 31, 2002, from pumping that took place after January 1, 1974, but before the date of the request; and those out-of-priority stream depletions that will affect the river for the eighteen months after the date of the request; except that out-of-priority stream depletions affecting the river from November 1, 2002, through June 15, 2003, may be remedied pursuant to agreements with all injured parties that are noticed in the request and approved as a part of the substitute water supply plan or an amendment thereto. The amount of such depletions shall be separately set forth in any plan approval issued by the state engineer. A substitute water supply plan approved pursuant to this subsection (3) shall require that the state engineer curtail all diversions, the out-of-priority depletions from which are not replaced as required by the plan.

(IV) Existing surface water rights may be used as a replacement water source in plans requested pursuant to this subsection (3), even if such rights have not been decreed for such use, but the substitute water supply plan shall prevent expanded use of such rights by imposing appropriate limitations, including, where appropriate, volumetric limitations on direct flow rights and shall require replacement of the historical return flows, including ditch seepage losses, from the use of such surface water rights in the time, location, and amount in which they occurred so that other water rights will not be injured. A request seeking to use existing surface water rights that have not been decreed for augmentation use shall include a calculation of the historical diversions and return flows, including estimated ditch seepage losses, attributable to such rights. The presumed amount of on-farm consumptive use from irrigation water rights shall not be more than fifty percent of the amount delivered to the farms; except that if a water court application has been filed and the proposed change of water right is approved as a separate substitute water supply plan pursuant to this section, such water rights shall be used in accordance with their own substitute water supply plan.

(V) Replacement water deliveries required by the substitute water supply plan shall be provided at the time and location necessary to satisfy the lawful requirements of a senior diverter. In determining the adequacy of the substitute water supply plan to prevent injury to water rights and decreed conditional water rights, the state engineer shall determine the amount of replacement water required for and available to the plan based upon current and projected hydrologic conditions.

(VI) If a substitute water supply plan covers wells, including augmentation wells, that are also covered by a decreed plan for augmentation or a separate substitute water supply plan, the accounting methodologies required by the decree or the separate plan shall control.

(VII) Substitute water supply plans that include or allow the use of augmentation wells shall include the terms and conditions needed to account for and replace all out-of-priority stream depletions that will result from their use, including post-pumping depletions. Beginning January 1, 2006, ground water diversions from all such augmentation wells shall be continuously curtailed unless the wells are included in a plan for augmentation approved by the water judge for water division 1, a substitute water supply plan approved pursuant to subsection (4) of this section, or can be operated under their own priorities without augmentation.

(VIII) If amendments, including but not limited to the addition of more wells or the addition of different replacement water sources, are proposed to a substitute water supply plan after the initial written notice of the plan was given, the notice, comment, and hearing process described in this paragraph (c) shall be repeated for such amendments. If, in the opinion of the state engineer, an amendment is necessary to prevent immediate injury to other water rights that will occur prior to the expiration of the thirty-day comment period provided in subparagraph (III) of paragraph (b) of this subsection (3), the thirty-day comment period shall be shortened to fifteen days, the public hearing shall be held no later than twenty-five days after the date of the mailing of notice of the request for the amendment, and the amendment may be implemented before the comment deadline and the public hearing. For amendments implemented prior to a public hearing, the state engineer shall issue a decision approving or denying the amendment no later than seven days after the conclusion of the public hearing. The state engineer may revoke or further condition the approval of any amendment after the comment and hearing process.

(IX) A substitute water supply plan approved pursuant to this subsection (3) shall include a requirement for monthly accounting to be compiled for every month of each year. Such accounting shall state the amount and location of the calculated depletions from all wells included in the plan, the amount, location, and source of all replacement water actually provided, and shall describe any other plan operations for that month. After the end of the water year, and no later than December 31 of each calendar year of plan operation, an annual accounting of all actual plan operations for the previous water year shall be compiled. Copies of both the monthly and annual accounting shall be provided to all parties that filed written comments concerning the plan pursuant to subparagraph (II) of paragraph (b) of this subsection (3).

(d) A substitute water supply plan approved pursuant to this subsection (3) shall not be approved for a period of more than one year; except that an applicant may request the renewal of a plan by repeating the application process described in this subsection (3); except that in no case shall a plan approved pursuant to this subsection (3) be renewed beyond December 31, 2005.

(e) When the state engineer approves or denies a substitute water supply plan, the state engineer shall serve a copy of the decision on all parties to the application by first-class mail or, if such parties have so elected, by electronic mail. Every decision of the state engineer shall provide a detailed statement of the basis and rationale for the decision, including a complete explanation of how all stream depletions were calculated, the location where they occur, how all replacement water sources were quantified, and what terms and conditions were imposed to prevent injury to other water rights and why they were imposed. The decision shall also include a description of the consideration given to any written comments that were filed by other parties. Neither the approval nor the denial by the state engineer shall create any presumptions, shift the burden of proof, or serve as a defense in any legal action that may be initiated concerning the substitute water supply plan. Any appeal of a decision made by the state engineer concerning a substitute water supply plan pursuant to this subsection (3) shall be made to the water judge in water division 1 within thirty days after the date of service of the decision. The water judge shall hear and determine such appeal using the procedures and standards set forth in sections 37-92-304 and 37-92-305 for determination of matters rereferred to the water judge by the referee. The proponent of the substitute water supply plan shall be deemed to be the applicant for purposes of application of such procedures and standards. The filing fee for the appeal shall be two hundred seventy-one dollars for the proponent of the substitute water supply plan and seventy dollars for any other party to the appeal. Moneys from such fee shall be transmitted to the state treasurer and deposited in the water adjudication cash fund, which fund is hereby created in the state treasury. The general assembly shall appropriate moneys in the fund for the judicial department's adjudications pursuant to this subsection (3).

(f) The state engineer may accept for filing and consideration a written request for approval of a substitute water supply plan prior to April 30, 2003, subject to such request meeting all requirements of this subsection (3) prior to the date of approval. No approval of such request may be issued prior to April 30, 2003.

(g) Repealed.

(4) (a) Beginning January 1, 2002, if an application for approval of a plan for augmentation, rotational crop management contract, or change of water right has been filed with a water court and the court has not issued a decree, the state engineer may approve the temporary operation of such plan, contract, or change of water right as a substitute water supply plan if the following conditions are met:

(I) The water court applicant has filed a request for approval of the substitute water supply plan with the state engineer;

(II) The applicant has provided written notice of the request for approval of the substitute water supply plan by first-class mail or electronic mail to all parties who have filed a statement of opposition to the plan in water court and proof of such notice is filed with the state engineer, or, if the deadline for filing a statement of opposition has not passed, the applicant has provided written notice of the request for approval of the substitute water supply plan by first-class mail or electronic mail to all parties who have subscribed to the substitute water supply plan notification list for the water division in which the proposed plan is located and proof of such notice is filed with the state engineer;

(III) The state engineer has given those to whom notice was provided thirty days after the date of mailing of such notice to file comments on the substitute water supply plan. Such comments shall include any claim of injury, any terms and conditions that should be imposed upon the plan to prevent injury to an opposer's water rights or decreed conditional water rights, and any other information an opposer wishes the state engineer to consider in reviewing the substitute water supply plan request.

(IV) The state engineer, after consideration of the comments received, has determined that the operation and administration of such plan will replace all out-of-priority depletions in time, location, and amount and will otherwise prevent injury to other water rights and decreed conditional water rights, including water quality and continuity to meet the requirements of use to which the senior appropriation has normally been put, pursuant to section 37-80-120 (3), and will not impair compliance with any interstate compacts. Notwithstanding any limitations regarding phreatophytes or impermeable surfaces that would otherwise apply pursuant to section 37-92-103 (9) or 37-92-501 (4) (b) (III), for any precipitation harvesting pilot project selected pursuant to section 37-60-115 (6) that has filed an application for a permanent augmentation plan in water court, the out-of-priority depletions shall be the net depletion as defined in section 37-60-115 (6) (c) (II) (B). As a condition of approving a substitute water supply plan for a pilot project pursuant to this subsection (4), the state engineer shall have the authority to require the project sponsor to replace any ongoing delayed depletions after the water use plan associated with a precipitation harvesting pilot project has ceased. The state engineer shall impose such terms and conditions as are necessary to ensure that these standards are met. In making such determinations, the state engineer shall not be required to hold any formal hearings or conduct any other formal proceedings, but may conduct a hearing or formal proceeding if the state engineer finds it necessary to address the issues.

(b) A substitute water supply plan approved pursuant to this subsection (4) shall not be approved for a period of more than one year; except that an applicant may request the renewal of a plan by repeating the application process described in this subsection (4). If an applicant requests a renewal of a plan that would extend the plan past three years from the initial date of approval, the applicant shall demonstrate to the state engineer that the delay in obtaining a water court decree is justifiable and that not being able to continue operating under a substitute water supply plan until a decree is entered will cause undue hardship to the applicant. A project sponsor for a precipitation harvesting pilot project selected pursuant to section 37-60-115 (6) shall demonstrate to the state engineer that an additional year of operation under the plan is necessary to obtain sufficient data to meet the Colorado water conservation board's criteria for evaluating the pilot project. If an applicant requests renewal of a plan that would extend the plan past five years from the initial date of approval, the applicant shall demonstrate to the water judge in the applicable water division that the delay in obtaining a decree has been justifiable and that not being able to continue operating under a substitute water supply plan until a decree is entered will cause undue hardship to the applicant. Approval of a plan pursuant to subsection (5) of this section shall be deemed to be approval under this subsection (4) for purposes of calculating the number of years since the initial date of approval.

(c) When the state engineer approves or denies a substitute water supply plan, the state engineer shall serve a copy of the decision on all parties to the pending water court application by first-class mail. Neither the approval nor the denial by the state engineer shall create any presumptions, shift the burden of proof, or serve as a defense in the pending water court case or any other legal action that may be initiated concerning the substitute water supply plan. Any appeal of a decision made by the state engineer concerning a substitute water supply plan pursuant to this subsection (4) shall be to the water judge of the applicable water division within thirty days and shall be consolidated with the application for approval of the plan for augmentation.

(5) (a) Beginning January 1, 2002, for new water use plans involving out-of-priority diversions or a change of water right, if no application for approval of a plan for augmentation or a change of water right has been filed with a water court and the water use plan or change proposed and the depletions associated with such water use plan or change will be for a limited duration not to exceed five years, except as otherwise provided in subparagraph (II) of paragraph (b) of this subsection (5), the state engineer may approve such plan or change as a substitute water supply plan if the following conditions are met:

(I) The applicant has filed a request for approval of the substitute water supply plan with the state engineer;

(II) The applicant has provided written notice of the request for approval of the substitute water supply plan by first-class mail or electronic mail to all parties who have subscribed to the substitute water supply plan notification list for the water division in which the proposed plan is located and proof of such notice is filed with the state engineer;

(III) The state engineer has given the owners of water rights and decreed conditional water rights thirty days after the date of mailing of such notice to file comments on the substitute water supply plan. Such comments shall include any claim of injury or any terms and conditions that should be imposed upon the plan to prevent injury to a party's water rights or decreed conditional water rights and any other information the opposer wishes the state engineer to consider in reviewing the substitute water supply plan request.

(IV) The state engineer, after consideration of the comments received, has determined that the operation and administration of such plan will replace all out-of-priority depletions in time, location, and amount and will otherwise prevent injury to other water rights and decreed conditional water rights, including water quality and continuity to meet the requirements of use to which the senior appropriation has normally been put, pursuant to section 37-80-120 (3) and will not impair compliance with any interstate compacts. The state engineer shall impose such terms and conditions as are necessary to ensure that these standards are met. In making the determinations specified in this subparagraph (IV), the state engineer shall not be required to hold any formal hearings or conduct any other formal proceedings, but may conduct a hearing or formal proceeding if the state engineer finds it necessary to address the issues.

(b) (I) Except as otherwise provided in subparagraph (II) of this paragraph (b), a substitute water supply plan approved pursuant to this subsection (5) shall not be approved for a period of more than one year; except that an applicant may request the renewal of a plan by repeating the application process described in this subsection (5). However, in no event shall any plan approved pursuant to this subsection (5) or any water use included in such plan be approved or renewed for more than five years.

(II) A project sponsor for a precipitation harvesting pilot project selected pursuant to section 37-60-115 (6) may request renewal of a plan that would extend the plan past five years from the initial date of approval if the project sponsor demonstrates to the state engineer that an additional year of operation under the plan is necessary to obtain sufficient data to meet the Colorado water conservation board's criteria for evaluating the pilot project or an application for a permanent augmentation plan is pending before the water court. As a condition of approving a substitute water supply plan for a pilot project pursuant to this subsection (5), the state engineer shall have the authority to require the project sponsor to replace any ongoing delayed depletions after the water use plan associated with a precipitation harvesting pilot project has ceased.

(c) When the state engineer approves or denies a substitute water supply plan, the state engineer shall serve a copy of the decision on all parties to the application by first-class mail or, if such parties have so elected, by electronic mail. Neither the approval nor the denial by the state engineer shall create any presumptions, shift the burden of proof, or serve as a defense in any legal action that may be initiated concerning the substitute water supply plan. Any appeal of a decision made by the state engineer concerning a substitute water supply plan pursuant to this subsection (5) shall be made to the water judge in the applicable water division within thirty days, who shall hear such appeal on an expedited basis.

(6) The state engineer shall establish a substitute water supply plan notification list for each water division for the purposes of notifying interested parties pursuant to subparagraph (II) of paragraph (b) of subsection (3) of this section and subparagraph (II) of paragraph (a) of subsection (5) of this section. Beginning in July 2002, and in January of each year thereafter, in order to establish such notification list, the water clerks in each division shall include in the water court resume an invitation to be included on such notification list for the applicable water division. Persons on the substitute water supply plan notification list shall receive notice of all substitute water supply plans filed in that water division pursuant to subsections (3) and (5) of this section by either first-class mail or, if a person so requests, by electronic mail. Persons may be required to pay a fee, not to exceed twelve dollars per year, to be placed on the notification list.

(7) Beginning January 1, 2002, the state engineer may approve a substitute water supply plan if the state engineer determines such plan is needed to address an emergency situation and that the plan will not cause injury to the vested water rights or decreed conditional water rights of others or impair compliance with any interstate compact. Such plan shall not be implemented for more than ninety days. For purposes of this section, "emergency situation" means a situation affecting public health or safety where a substitute water supply plan needs to be implemented more quickly than the other procedures set forth in this section allow. For 2003, an "emergency situation" may also mean an immediate need for the use of augmentation wells necessitated by extreme drought conditions if such augmentation wells are also included in a request filed previously, or filed simultaneously with a request under this subsection (7), for approval of a substitute water supply plan under subsection (3) or (4) of this section. Approval pursuant to this section of the use of augmentation wells shall include the terms and conditions needed to account for and replace all out-of-priority stream depletions that will result from such use, including post-pumping depletions. Within five days after the date of approval of the use of an augmentation well under this subsection (7), the state engineer shall give notice of the approval to all parties who have subscribed to the substitute water supply plan notification list for water division 1. In all other situations, notice to other water users shall not be required. Neither the approval nor the denial by the state engineer shall create any presumptions, shift the burden of proof, or be a

defense in any legal action that may be initiated concerning an emergency substitute water supply plan or in any proceedings under subsection (3) or (4) of this section.

(8) After July 1, 2002, water users requesting approval of a new plan or a substitute water supply plan pursuant to this section shall pay a fee of three hundred dollars. The fees shall be used by the state engineer for the publishing and administrative costs for processing applications and renewals and administering plans. Such fees shall be deposited in the ground water management cash fund pursuant to section 37-80-111.5.

(9) If an entity pays for repairs, maintenance, dredging, or other improvements, including capital improvements, that are necessary and effective in removing a storage restriction imposed by the state engineer pursuant to section 37-87-107 on a dam or reservoir owned by a third party, such entity may apply to the state engineer pursuant to subsection (5) of this section for approval of the use of some or all of such newly unrestricted storage as a substitute water supply plan, if the entity has a written agreement concerning such use with all the owners of the dam or reservoir and the associated water rights.

(10) (a) Beginning July 1, 2009, for plans for augmentation that are the subject of a final decree entered by the water court in water division 1, the state engineer may approve annual substitute water supply plans solely for the purpose of allowing the use of water supplies not identified as augmentation supplies in the decreed augmentation plan, not previously decreed for augmentation or replacement uses, and not included in a pending water court application for approval of a change of water right to augmentation and replacement uses to be used in the decreed augmentation plan for the replacement of out-of-priority depletions caused by pre-January 1, 2003, diversions from wells included in the decreed augmentation plan, subject to and in accordance with the terms and conditions of the decreed augmentation plan. No water supplies for which substitute water supply plan approval is requested pursuant to this subsection (10) shall be used by an applicant for augmentation purposes prior to the date on which the state engineer approves the substitute water supply plan or the date on which any appeal to the water court of the substitute water supply plan is finally decided in accordance with paragraph (d) of this subsection (10), whichever occurs later. The state engineer may approve a substitute water supply plan under this subsection (10) if the following conditions are met:

(I) The applicant has filed a request for approval of the substitute water supply plan with the state engineer, which request shall include, at a minimum, the following information:

(A) The name of the water rights to be used for augmentation in the decreed augmentation plan under the substitute water supply plan and a list of decrees associated with such rights;

(B) A copy of every agreement or other document that evidences the applicant's right to use the water rights for augmentation;

(C) For use of existing South Platte river basin surface water rights, an analysis of the historical use of the water rights, which analysis shall include, at a minimum, the location and number of acres historically irrigated by the rights, identification of the crops historically irrigated by the rights, a calculation of the historical diversions and return flows associated with historical use of the rights, a summary of average annual diversions and average and maximum monthly diversions and consumptive use associated with historical use of the rights, the field irrigation efficiency used in the historical use analysis, which shall not exceed fifty percent, and the identity of all other water rights used to irrigate the land historically irrigated by the water rights;

(D) The amount of water available from the water rights for replacement uses under the substitute water supply plan;

(E) The amount of return flows, if any, associated with the historical use of the water rights, including the amount and timing of such return flows that would occur after the end of the one-year substitute water supply plan approved under this subsection (10);

(F) The amount of depletions from pre-January 1, 2003, diversions to be replaced using the water rights;

(G) The source of water to be used to make required return flow replacements, which source shall not include water pumped from augmentation wells;

(H) The manner in which the applicant will incorporate the accounting for use of the water rights for augmentation uses into the accounting required by the augmentation plan decree and make any required return flow replacements under the substitute water supply plan; and

(I) For use of existing South Platte river basin surface water rights, an affidavit signed by the record owner of the water rights stating that, during the term of the substitute water supply plan, the land historically irrigated by the water rights shall not be irrigated except with nontributary ground water or potable water supplied by a municipality or water district;

(II) The applicant has provided written notice of the request for approval of the substitute water supply plan and has made available the information required in subparagraph (I) of this paragraph (a), by first-class mail or electronic mail, to all parties who have subscribed to the substitute water supply plan notification list for water division 1 and all parties to the water court case in which the plan for augmentation was decreed, and proof of such notice is filed with the state engineer;

(III) The state engineer has given the owners of water rights and decreed conditional water rights and the parties to the water court case in which the plan for augmentation was decreed thirty days after the date of mailing of such notice to file comments on the substitute water supply plan. Such comments shall include any claim of injury or any terms and conditions that should be imposed upon the plan to prevent injury to a party's water rights or decreed conditional water rights and any other information the opposer wishes the state engineer to consider in reviewing the substitute water supply plan request.

(IV) The state engineer, after consideration of the comments received, has determined that the operation and administration of such plan will, when combined with replacements under the decreed augmentation plan, replace all out-of-priority depletions caused by the pre-January 1, 2003, diversions from wells included in the decreed augmentation plan in time, location, and amount required by the decree, and will otherwise prevent injury to other water rights and decreed conditional water rights, including water quality and continuity to meet the requirements of use to which the senior appropriation has normally been put pursuant to section 37-80-120 (3), and will not impair compliance with any interstate compacts. The state engineer shall impose such terms and conditions as are necessary to ensure that these standards are met, including, but not limited to, the terms and conditions required by paragraph (b) of this subsection (10). In making the determinations specified in this subparagraph (IV), the state engineer shall not be required to hold any formal hearings or conduct any other formal proceedings, but may conduct a hearing or formal proceeding if the state engineer finds it necessary to address the issues.

(b) The following terms and conditions shall be included in any substitute water supply plan approved pursuant to this subsection (10):

(I) For use of existing South Platte river basin surface water rights, the land historically irrigated by such water rights shall not be irrigated during the term of the substitute water supply plan except with nontributary ground water or potable water supplied by a municipality or water district. Where the historically irrigated crop is alfalfa, an appropriate reduction in the allowable consumptive use credit shall be imposed if the alfalfa has not been completely removed from the historically irrigated land during the term of the substitute water supply plan.

(II) For use of existing South Platte river basin surface water rights, an annual volumetric limit on diversions and a monthly volumetric limit on diversions, which shall not be greater than the average annual and maximum monthly historical diversions of the water rights.

(III) For use of existing South Platte river basin surface water rights, all return flows that would have accrued to the stream from the historical use of the water rights shall be replaced, including the return flows that would have occurred after the end of the one-year substitute water supply plan. All such return flows shall be deemed to be an obligation of the applicant for the substitute water supply plan and shall be included as a replacement obligation in any projection required by the augmentation plan decree in which such water is proposed to be used, and after the end of any approved substitute water supply plan, all continuing return flow obligations shall be enforceable in the same manner as all other terms and conditions of the augmentation plan decree under which the water rights in the substitute water supply plan were used.

(IV) For use of existing South Platte river basin surface water rights, no water pumped from augmentation wells, as such wells are defined in section 37-90-103 (21) (a), shall be used to replace return flows that would have accrued to the stream from the historical use of the water rights.

(V) The amount of water made available under the approved substitute water supply plan shall not be included as a source of water for replacement of depletions in any projection required by the augmentation plan decree in which such water is proposed to be used until the substitute water supply plan is approved, and then only for the term of the approved substitute water supply plan or the term of the agreement or other document which evidences the applicant's right to use the water rights for augmentation, whichever is shorter.

(VI) The accounting for the approved substitute water supply plan shall be incorporated into the accounting for the augmentation plan decree in which such water is proposed to be used and shall be shown in the accounting in separate line items. Such accounting and all supporting documents for such accounting shall be provided by the applicant to any party requesting such accounting and supporting documents in writing and upon payment of reasonable reproduction costs.

(VII) If any term or condition of the approved substitute water supply plan conflicts with any of the terms and conditions of the augmentation plan decree, the terms and conditions of the augmentation plan decree shall control.

(c) A substitute water supply plan approved pursuant to this subsection (10) shall not be approved for a period of more than one year; except that an applicant may request the renewal of a plan by repeating the application process described in this subsection (10). However, in no event shall an individual water right or source of water native to the South Platte river basin, including the pro rata portion of a water right represented by shares in a mutual ditch company, be approved for use in a substitute water supply plan approved pursuant to this subsection (10) for a total of more than five years.

(d) When the state engineer approves or denies a substitute water supply plan pursuant to this subsection (10), the state engineer shall serve a copy of the decision on all parties who have subscribed to the substitute water supply plan notification list for water division 1 and all parties to the water court case in which the plan for augmentation was decreed by first-class mail or, if such parties have so elected, by electronic mail. Neither the approval nor the denial by the state engineer shall create any presumptions, shift the burden of proof, or serve as a defense in any legal action involving the substitute water supply plan. Any appeal of a decision made by the state engineer concerning a substitute water supply plan approved or denied pursuant to this subsection (10) shall be made within thirty days after the date of service of the decision. Any such appeal shall be filed under the same case number as the decreed plan for augmentation and shall be heard under the retained jurisdiction of the water judge, using the procedures and standards set forth in sections 37-92-304 and 37-92-305, for determination of matters rereferred to the water judge by the referee. The water judge shall hear and determine any such appeal on an expedited basis. The applicant for the substitute water supply plan shall not use the proposed substitute water supply in the decreed plan for augmentation until any appeal under this paragraph (d) is decided by the water court. Following the determination on appeal by the water court, the applicant's use of water under the substitute water supply plan shall be governed by such water court determination, unless the terms of the augmentation plan decree provide otherwise.

(e) Nothing in this subsection (10) shall authorize or facilitate additional transbasin diversion of water from the Colorado river.

(f) (I) This subsection (10) is repealed, effective July 1, 2018.

(II) All approvals of substitute water supply plans under this subsection (10) shall expire on or before July 1, 2018.

(11) (a) (I) To provide sufficient time to integrate coal bed methane wells into the water court adjudication process for augmentation plans, during 2010, 2011, and 2012 the state engineer may approve annual substitute water supply plans for such wells using the procedures and standards set forth in this subsection (11). Until July 31, 2010, coal bed methane wells may continue to operate without a substitute water supply plan if the oil and gas operator submits a request for approval of a substitute water supply plan pursuant to this subsection (11) by April 30, 2010. Beginning August 1, 2010, and ending December 31, 2012, no coal bed methane well that withdraws tributary ground water and impacts an over-appropriated stream shall operate unless:

(A) Operation of the well is authorized pursuant to this section;

(B) The well is included in a plan for augmentation approved by a water judge; or

(C) The well is included in a substitute water supply plan approved pursuant to subsection (4) of this section.

(II) Beginning January 1, 2013, any coal bed methane well that withdraws tributary ground water from a geologic formation in conjunction with the mining of minerals shall be continuously curtailed unless the well:

(A) Is included in a plan for augmentation approved by a water judge;

(B) Is included in a substitute water supply plan approved pursuant to subsection (4) of this section; or

(C) Can be operated in priority without augmentation.

(III) The general assembly finds that the time period established in subparagraph

(II) of paragraph (b) of this subsection (11) is sufficient to develop augmentation plan applications for these wells, and there shall be no subsequent extensions of this deadline.

(b) For a substitute water supply plan pursuant to this subsection (11), the state engineer may approve the temporary operation of a coal bed methane well that withdraws tributary ground water only if the following conditions are met:

(I) The applicant has provided written notice of the request for approval of the substitute water supply plan by first-class mail or electronic mail to all parties who have subscribed to the substitute water supply plan notification list for the water division in which the proposed plan is located and proof of such notice is filed with the state engineer;

(II) All parties who have subscribed to the substitute water supply plan notification list for the water division in which the proposed plan is located have thirty days after the date of mailing of such notice to file comments on the substitute water supply plan. Such comments shall include any claim of injury, any terms and conditions that should be imposed upon the plan to prevent injury to a party's water rights or decreed conditional water rights, and any other information a party wishes the state engineer to consider in reviewing the substitute water supply plan request; and

(III) The state engineer, after consideration of the comments received, has determined that the operation and administration of such plan will: Replace all out-of-priority depletions occurring on or after June 2, 2009, in time, location, and amount, including delayed out-of-priority depletions that affect the stream system after expiration of the plan; otherwise prevent injury occurring on or after June 2, 2009, to other water rights and decreed conditional water rights, including water quality and continuity to meet the requirements of use to which the senior appropriation has normally been put pursuant to section 37-80-120 (3); and not impair compliance with any interstate compacts. The state engineer shall impose such terms and conditions as are necessary to ensure that these standards are met, which may include terms and conditions that remain in effect after expiration of the plan so as to require the proponent of the plan to replace delayed out-of-priority depletions occurring on or after June 2, 2009. In making such determinations, the state engineer shall not be required to hold any formal hearings or conduct any other formal proceedings, but may conduct a hearing or formal proceeding if the state engineer finds it necessary to address the issues.

(c) A substitute water supply plan approved pursuant to this subsection (11) shall not be approved for a period of more than one year; except that an applicant may request the renewal of a plan by repeating the application process described in this subsection (11). In no case shall a plan approved pursuant to this subsection (11) be renewed beyond December 31, 2012.

(d) When the state engineer approves or denies a substitute water supply plan, the state engineer shall serve a copy of the decision on all parties to the substitute water supply plan notification list for the water division in which the proposed plan is located by first-class mail or by electronic mail. Every decision of the state engineer shall provide a detailed statement of how all stream depletions were calculated, the location where they occur, how all replacement water sources were quantified, and what terms and conditions were imposed to prevent injury to other water rights and why they were imposed.

(e) Neither the approval nor the denial by the state engineer shall create any presumptions, shift the burden of proof, or serve as a defense in any legal action that may be initiated concerning the substitute water supply plan. Any appeal of a decision made by the state engineer concerning a substitute water supply plan pursuant to this subsection (11) shall be to the water judge of the applicable water division within thirty days after the date of service of the decision. The water judge shall hear and determine such appeal on an expedited basis using the procedures and standards set forth in sections 37-92-304 and 37-92-305 for determination of matters referred to the water judge by the referee.

Source: L. 2002: Entire section added, p. 459, § 1, effective May 23. **L. 2003:** IP(4)(a), (4)(a)(II), (4)(a)(III), (4)(a)(IV), (4)(b), IP(5)(a), (5)(a)(IV), and (5)(b) amended and (9) added, p. 1368, § 5, effective April 25; (1)(c), (2), (3), (6), and (7) amended, p. 1446, § 1, effective April 30; (1)(b) amended, p. 2002, § 64, effective May 22. **L. 2004:** (3)(a) amended, p. 1205, § 80, effective August 4. **L. 2006:** IP(4)(a) amended, p. 1002, § 4, effective May 25. **L. 2008:** (3)(g) repealed, p. 1913, § 128, effective August 5. **L. 2009:** (10) added, (SB 09-147), ch. 108, p. 449, § 1, effective April 9; (4)(a)(IV), (4)(b), IP(5)(a), and (5)(b) amended, (HB 09-1129), ch. 389, p. 2104, § 2, effective June 2; (11) added, (HB 09-1303), ch. 390, p. 2110, § 6, effective June 2. **L. 2010:** IP(11)(a)(I) amended, (SB 10-165), ch. 31, p. 113, § 3, effective March 22.

Editor's note: Section 4 of chapter 31, Session Laws of Colorado 2010, provides that the act amending the introductory portion to subsection (11)(a)(I) applies to conduct occurring on or after March 22, 2010.

ANNOTATION

Law reviews. For article, "Substitute Supply Plans: Recent Water Law Developments", see 31 Colo. Law. 67 (August 2002).

State engineer's authority under this section is limited. Legislative history demonstrates that the general assembly intended approval of all out-of-priority uses of water involving replacement water to be the sole province of the water courts, with the exception of the limited circumstances provided for in subsections (3), (4), (5), and (7) of this section and in §§ 37-80-120 (5) and 37-90-137 (11)(b). Simpson v. Bijou Irrigation Co., 69 P.3d 50 (Colo. 2003).

"Replacement plan" defined. A "replacement plan", as used in this section and the state engineer's proposed rules, is the functional equivalent of a "substitute supply plan" and refers to the source of water that a junior or undecreed well user makes available to a senior appropriator to offset any injury caused to the senior by the junior's or undecreed well user's out-of-priority depletions. Simpson v. Bijou Irrigation Co., 69 P.3d 50 (Colo. 2003).

Augmentation plan defined. An augmentation plan is the functional equivalent of a substitute supply plan or "replacement plan" but, significantly, has been sanctioned by court decree and thereby renders the out-of-priority diversion no longer susceptible to curtailment by the state engineer pursuant to §§ 37-92-501 (1) and 37-92-502 (2)(a), so long as the replacement water is supplied to avert injury to senior rights. Simpson v. Bijou Irrigation Co., 69 P.3d 50 (Colo. 2003).

Limitations in this section apply to rules adopted by the state engineer pursuant to the compact rule power granted by § 37-80-104, as well as to those adopted pursuant to the water rule power granted by § 37-92-501. Simpson v. Bijou Irrigation Co., 69 P.3d 50 (Colo. 2003).