HydroBio
Advanced Remote Sensing

A response to:
Colorado Potato Administrative Committee 2012 Request for Proposals for Funding
(Research Priority: Crop Production Practices to Optimize Profitability Through Increased Irrigation Efficiency)

1. Title: Targeted Irrigation Management to Increase Irrigation Efficiency (TIM)

2. Most relevant funding source: CPAC

3. Investigator Name: Dr. David Groeneveld, President of HydroBio, Advanced Remote Sensing of Santa Fe, New Mexico.

4. Nature, scope, objective of proposed research:

The objective of this project is to test and calibrate targeted irrigation management (TIM) and to demonstrate the water and energy conservation that can be achieved in San Luis Valley (SLV). TIM is being developed to be an affordable automated service that prescribes and controls irrigation remotely through Internet and wireless connectivity.

This project will answer the need for deep water conservation for all crops in the SLV, not just potatoes. Water savings provided for all crops can result in more water available within the SLV, reducing the overall strain on the groundwater and costs for potato grower. The overall project is $121,588, with an in kind match by HydroBio of $91,191 (3/4 of total): HydroBio requests CPAC funds of $30,397. Two cooperating companies will provide their services gratis for this project.

4a. Objectives of This Proposal

TIM has the potential to change irrigation practices in SLV, virtually overnight. The positive impacts to water users can be enormous. This technology is being tested in the SLV to evaluate its potential to achieve water and energy conservation and to demonstrate its capability to local growers.

Beta testing will proof and enhance TIM for use on SLV's main crops, alfalfa, potatoes, and barley. In addition to proofing and enhancement, this program will demonstrate the technology, its accuracy, and the certainty it can bring for water and power conservation in SLV irrigation. Because there is a general tendency for most growers to water in excess of crop requirements, TIM can provide the opportunity to achieve deep water conservation while not impacting yields. TIM has the potential to save many tens of thousands of acre feet of SLV irrigation each year.

This program will establish TIM calculations across the SLV and will make irrigation prescriptions for multiple pivots of the three target species. These prescriptions will be

compared to those made using crop coefficients. The TIM program will be automated and administered through Internet connectivity—irrigation prescriptions will be presented graphically for each field.

4b. Three Cooperating Companies

Three companies that bring an optimal science, computation, agronomy, technology and local knowledge have teamed for this program.

HydroBio is a remote sensing and GIS company that has pioneered methods for estimating the water consumption of crops and native vegetation. HydroBio consulted to the Rio Grande Water Conservation District (RGWCD) Board 1995 to 2004 on the ecology and water use of native vegetation in the San Luis Valley and staff has written and published four papers covering this work. HydroBio is the originator of RDC, the method for estimating the water use of crops and is the patent holder on TIM.

HydroBio will provide computer tracking of crop water requirements and weather to perform computation of irrigation prescriptions for the fields selected for the project. These fields will include the Center Conservation District/RGWCD Demonstration Farm (Demo Farm). HydroBio will be responsible for maintaining thorough and open communication for all project participants and for outreach—two activities that will ensure the success of TIM testing and outreach. HydroBio will interface with PivoTrack Monitoring to provide daily-updated data for each field enrolled in the program and with Agro Engineering to include their agronomic and local knowledge. These project fields will be accessible by the project participants and only with their agreement, made available online to the public.

Agro Engineering (Agro), of Monte Vista, is the major source of agronomic expertise and trusted advisors to growers in the San Luis Valley. Agro brings their years of experience and tuned local knowledge to the proposed study.

Agro will provide testing of field properties to assist in the TIM calculations, will cooperate with HydroBio for programming flexible irrigation rules to assist the TIM expert system for the three crops to be included in the study, alfalfa and potatoes. Agro will also provide on site services to the telemetry equipment on the Demo Farm field, if needed. Agro will track the TIM calculations through the summer for comparison to water use calculations made using k factors and local reference ET. Agro's intensive service to SLV agriculture will ensure that no aspect related to irrigation and irrigation timing is overlooked and that TIM gets a thorough evaluation and input for adjustment if needed.

PivoTrack Monitoring (PTM), of Dalhart, Texas, is a company that provides services for remote pivot monitoring and control to thousands of growers across the Texas Panhandle (TXP). PTM is noted for its highly professional telemetry system and connectivity that has proven highly reliable. PTM programs have enabled a revolution in remote pivot control and irrigation safety (alerts are given for pivot stops, and water pressure problems) so that Panhandle growers can rest assured that their crops are being watered as prescribed.

PTM will provide remote service and a website to deliver the results to program participants and, with their agreement, to the public. PTM and HydroBio are also cooperating on a ground breaking and highly visible water conservation program that will employ TIM in the TXP, so cross fertilization of this SLV effort with the TXP program is expected.

4c. TIM Background

TIM is an irrigation forecasting, accounting and control package for internet based irrigation management applied through remote monitoring and control services, now commonly being used on pivot systems, especially in water-short regions (PTM, serving Panhandle is an example of this technology). At the heart of TIM is HydroBio's patent pending method to assess crop water requirement, called Remotely-sensed Dual Coefficient (RDC) that is based upon the standard dual coefficient method used in agriculture. Earth observation satellite (EOS) data are used to estimate the water requirement of the crop when combined with weather data and reference evapotranspiration (ETo; a measure of the evaporative driving force based on daily weather conditions).

For RDC calculations of water use, a vegetation index developed by HydroBio, derived from EOS data, is used to determine the status of the crop canopy as an estimate of the relative canopy chlorophyll content. This use is analogous to growth-stage specific k factors often used for estimating crop water use when multiplied by reference ET, but is more accurate because, rather than using a time-specific approximation, RDC provides a k factor specific to the crop for each sub-acre pixel across each field at the time of the overpass.

RDC has proven accurate without modification for a wide variety of crops including alfalfa, corn, soybeans, and milo, and across several different methods of water supply. For example, results from tests on corn grown in the Panhandle are shown in Figure 1. San Luis Valley crops will undergo testing using RDC from archived satellite and weather data that will be compared to actual irrigation records and k-factor derived estimates of water use.

4d. Benefits of TIM

There are several major benefits of TIM for irrigators. TIM removes the guesswork for water application and provides convenience and certainty by applying a prescription for the water required by each cropped field. TIM must be demonstrated thoroughly to growers to ensure that they understand and trust the prescription. Because of the large investment a crop represents, full application of TIM, including automatic irrigation may be a couple years away in SLV, even with successful demonstration. This proposal is intended to be the first of several steps needed to get to full TIM operation however, this initial step is crucial for testing, enhancement and introduction to SLV. Once adopted, the

same level of savings in irrigation costs and water can be enjoyed by every SLV grower within several years.

In full operation TIM will perform accounting to estimate the crop water needs and forecast ahead so that the crop is not placed in jeopardy because conservation did not anticipate high water demand during the driest and hottest portions of the growing season, often, a period when the sprinkler system cannot catch up to the crops needs. This requires looking ahead so that during the period of greatest potential crop water stress, generally in early July, the rate of application does not fall behind what the crop needs. In many locations, especially in the Panhandle, soil moisture storage provides this certainty. Soil moisture reserves are an important part of the TIM calculations. Agro brings significant value to the program because of their knowledge for rooting depth and water use of the major crops in SLV.

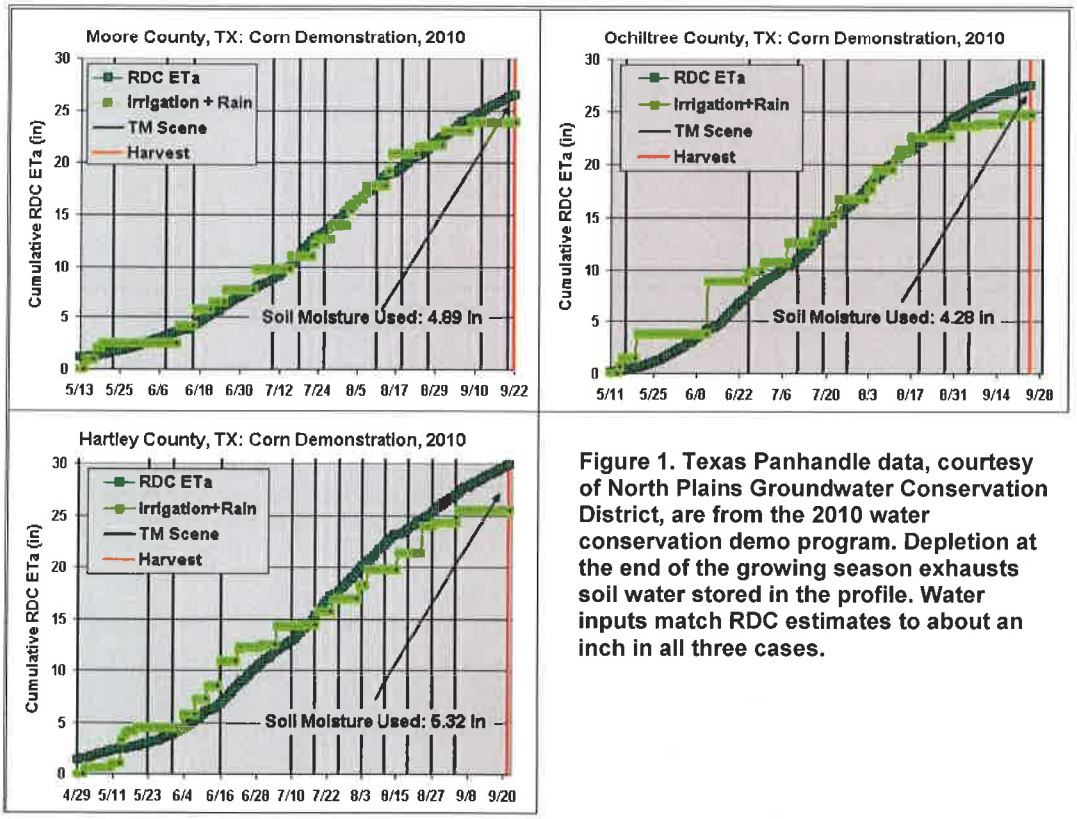

Figure 1. Texas Panhandle data, courtesy of North Plains Groundwater Conservation District, are from the 2010 water conservation demo program. Depletion at the end of the growing season exhausts soil water stored in the profile. Water inputs match RDC estimates to about an inch in all three cases.

TIM application will conserve water and energy since only the required water is provided for the crop. In automated mode, TIM schedules and applies irrigation and this can be targeted for nighttime or during periods when power rates are lower—thus, effectively gaming the system to save the most amount of input cost. However, such nighttime irrigation may subject the crop to disease and must always be factored into the decisions.

Agro's local knowledge will be valuable for navigating this and other issues related to irrigation (e.g., soil cooling soil from irrigating with surface water retards growth).

TIM has been being formulated to work with remote monitoring packages. Records established with RDC and TIM provide data that can be mined to plan enhancement for crop production while also achieving conservation of inputs.

TIM algorithms will account for soil water storage of multiple-day supplies for the crop's water requirement with strategies applied to optimize its use. Such storage begins with soil water content at germination that can be determined by direct measurements in a few locations that are extrapolated using spatial maps of precipitation that occurred over winter combined with accounting procedures. Regional calibration of the effects of irrigation and rainfall on soil water storage may eventually bypass the need for actual soil water measurements, an example that underscores the importance of mining and comparison of stored data.

Irrigation for crop germination and establishment also adds to the soil water bank. All inputs, both irrigated or rainfall, and ET outputs are accounted for in the TIM program. Due to the intensive interplay of data and careful scheduling of irrigation, no percolation from the root zone is anticipated. However, in cases of saline soils and/or irrigation water, leaching fractions can be calculated with the irrigation supply simply as a percentage above the actual irrigation requirement.

At the end of the growing season, the shutoff of irrigation can take place through rational planning so that the crop-available soil water stored in the profile is exhausted as is shown in the three examples in Figure 1. In this manner the soil system is poised to again receive recharging water from winter and spring precipitation. Such soil water storage-based accounting permits rational planning of irrigation strategies and these strategies can be encoded within TIM algorithms for a crop water supply that balances conservation with appropriate safety margins.

Finally, as mentioned before, once the value and accuracy of TIM is proven, it can be applied across the entire San Luis Valley within a couple of years. TIM provides irrigation certainty both by providing the exact crop requirement (with a leaching fraction, if needed), and providing feedback for the grower so that any issues in irrigation can immediately be flagged for attention (e.g., drop in pressure or pivot stranded in one location during irrigation). Providing certainty and feedback and saving water are simple functions that can revolutionize pivot irrigation in SLV save many tens of thousands of acre feet in water and lower the input costs for the farming community.

A crucial part of this proposed demonstration is the use of automated control on the Demo Farm pivot system administered through the Internet by wireless connectivity. Although automated watering is the ultimate goal, TIM water prescriptions will be provided as advisory until a level of comfort is reached with the Demo Farm Grower Mr.

Jason Benton. Calculations based upon K factors and local ETo will also be provided. These prescriptions can be delivered as suggested watering prescriptions for Mr. Benton to follow (or amend), or run as an entirely automated program but with calculations provided in a graphic, readily interpretable format to aid irrigation decision making with a sense of certainty. The same arrangement will be followed for the 15 other pivots that will be part of this program.

Another part of the proposed program is to proof the prescriptions that are made in an automated fashion by TIM. The automation provided by TIM can greatly reduce costs and so can be economically adopted across the SLV region in the interest of water conservation. In addition to the Demo Farm pivot, the program will also work with Agro to evaluate the TIM prescriptions for five pivots of the three most important SLV crops, potatoes, alfalfa and barley. This evaluation will compare watering prescriptions made by traditional method that employs k-factors.

5. Methods and facilities, including resource needs at the SLVRC

The Demo Farm to be used in the 2012 TIM program is located to southwest of Center (Figure 2) . The 2012 crop will provide soil rehabilitation using alfalfa as the planted crop. Although this crop is not potatoes, alfalfa is acceptable for beta testing in preparation for potatoes. Using the Demo Farm for beta testing TIM is an excellent use of CPAC funds because they support a service that promises the same benefits for potato growing. Potatoes require much simpler approaches for watering strategies because the numerous cuttings of alfalfa constitute a complex watering problem with multiple possible solutions. For this reason, a high level of communication will be sought with the Mr. Benton who has agreed to work closely with HydroBio and Agro.

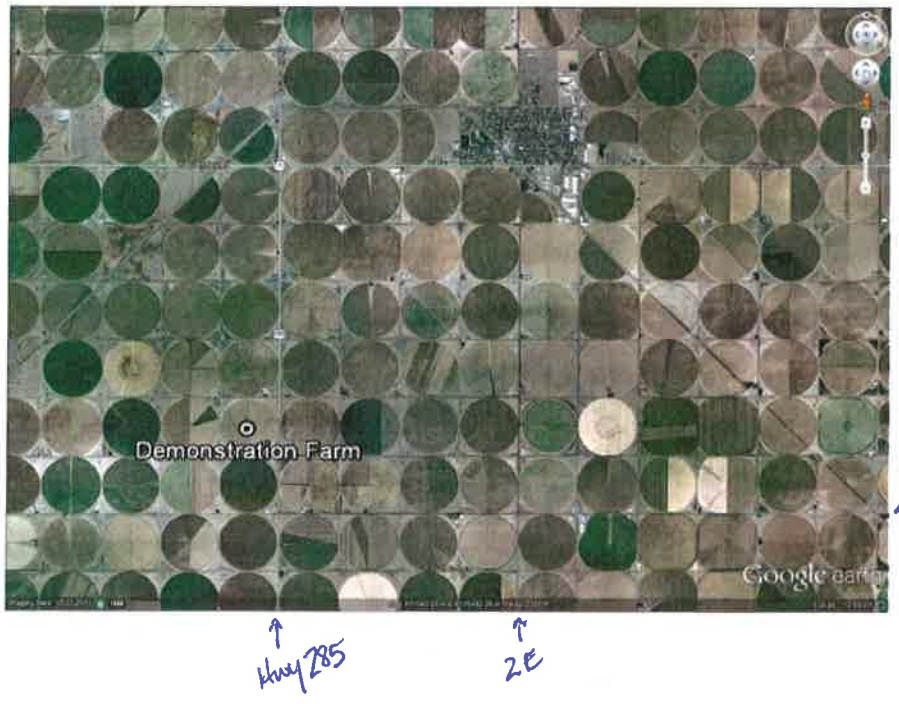

Figure 2. Image of the Demo Farm from Google Earth™.

5a. Program for 2012

The program proposed for 2012 is:

1. Analyze historic satellite and weather data in the Center, Colorado area for comparison of TIM estimates of crop water consumption to irrigation records and k-factor based estimates of water use for fields identified by Agro. The three major SLV crop types to be analyzed are potatoes, alfalfa and barley. Multiple examples of these fields will be tested (five each).
2. Purchase and outfit the Demo Farm with the telemetry equipment and and instrument package. The package will communicate with the PTM system through cell phone. The PTM website will host the data for the CPAC program in easily interpretable graphic format that, with grower OK, will be available for the public to access and follow through the season. The instrument package will include a shortwave solar radiation sensor, a tipping bucket rain gage, a soil moisture probe, a sensing system to report irrigation flow and a geographic positioning system.
3. Agro will identify five fields each for the three major crops for inclusion in the CPAC program. Agro will provide in-field data gathered through their agronomic activities and meter readings and dates for irrigation accounting. In this manner, Agro will provide the same data feedback as that provided automatically from the instrumentation at the Demo Farm.
4. HydroBio will run TIM calculations for all 16 center pivots—the Demo Farm and five other pivots planted to alfalfa, and five each barley and potatoes. HydroBio will analyze the data and make comparison of the TIM results in cooperation with Agro and provide a report at the end of the season (completed by December 1, 2012).
5. HydroBio will provide presentations to district board meetings, including the RGWCD and Center Irrigation District, to CPAC, and to other collective groups involved with farming in SLV.
6. HydroBio will present the results of the investigation at 2013 Southern Rocky Mountain Agricultural Conference.

The only facilities necessary for this work are the Demo Farm. Other facilities necessary will be meeting rooms to hold presentations and discussion at least for kickoff of the program and again at the end of season results and others as opportunities arise. The two meetings will be engineered with CPAC assistance to be as inclusive of SLV producers and conservation boards as possible. HydroBio will seek such open communication with CPAC assistance.

Purchases of equipment will be necessary for instrumentation of the Demo Farm. A nominal amount is requested for support to purchase these instruments and after the program the purchased instruments (flow meter telemetry, tipping bucket rain gage and shortwave solar radiation sensor will remain with the Demo Farm Pivot fro future use. The advantage to the instrumentation and the TIM program is that the data from the

Demo Farm (and all farms enrolled in the program) will be permanent digital records for future analysis.

The instrument package for the Demo Farm pivot will include:

- One soil moisture probe with telemetry.
- Flow meter telemetery (we understand that this pivot is metered)
- GPS tracking (end of pivot) that through telemetery tells the position of the irrigation boom.
- Tipping bucket rain gage, telemetered.
- Shortwave solar sensor (70% of ETo is solar radiation), telemetered.
- AquaSpy automated soil water sensor that measures soil water to five feet deep, telemetered,

EOS data will need to be purchased for this project and this and the cost of the instrument package and cellular service are provided in the detailed budget. Although Landsat ETM7 data are available every 16 days, there will periods when clouds obscure the field. Also, the ETM7 data have missing data stripes due to a malfunction of the instrumentation and so some fields may lack complete coverage—potentially missing up to 20% of the area. The good news is that ETM7 data are free. The bad news is that additional EOS data will need to be purchased. The most cost effective add-on data available is from a satellite named Deimos that is available for $1,200 per scene. Money has been budgeted for purchase of these data.

6. How the project will enhance the competiveness of Colorado potato growers

TIM will enhance SLV competiveness by reducing input costs while leaving yields either untouched or slightly improved. Over watering can impact yields for a variety of reasons, including leaching nutrients from the root zone, reduced root zone oxygen, promotion of root rot and soil chilling that retards crop growth and production—all factors that reduce yield. The effects of these negative influences are controlled by irrigating only what the crop requires. More importantly, irrigation is costly both in terms of water and power and the conservation enabled through TIM will insure that the grower takes more profit.

The cost of irrigation can be immense. For example, the 2012 surcharge for groundwater use imposed by RGWCD is $75/AF (www.rgwcd.org). For pivots served solely by groundwater, this can require up to $20,000 per season. A savings of 15 to 20% through use of TIM in this case could save between $3,000 and $4,000 annually. Such savings are possible because the uncertainty for watering is easily within the 15-20% range. For example, take a required watering event of say, one inch to replenish soil moisture to the required the level, the uncertainty would be about 0.15 to 0.2 inch. Faced with uncertainties in measuring and estimating the supply for their crop and without the sensitive yardstick provided by TIM, growers will tend to err on the side of keeping the crop "wet", and so, lose the potential for conservation, spending more for their

groundwater surcharge (up to $4,000 per season) and spending more money for power to pressurize and operate the sprinkler system.

By watering according to the careful prescription provided by TIM, an expected level of fallowing of land in SLV required to maintain Rio Grande instream flows may likely be reduced. Groundwater modeling indicates that about 60,000 acres of farmland (equivalent to 500 120-acre pivots) may need to come out of production to curtail depletion of interstate flows. The potential conservation provided by TIM, possibly ranging between 15 and 20% could considerably reduce the need to take pivots out of use (2700 pivots x 0.15 = 405 pivots; 2700 pivots x 0.2 = 540 pivots).

Receiving TIM scheduling from HydroBio will allow growers to irrigate remotely, without having to be physically present in the fields and to monitor that the application is, or has been, successful. This service provides certainty that the crop is receiving just the right amount of water, provides feedback if some issue arises during the irrigation and, rather than having to switch the irrigation on and off and monitor the pivot continuously, frees the grower for other tasks.

7. Extension-outreach plan for reporting project information to growers

The following outreach programs are planned:

(1) A kickoff meeting describing the program will be scheduled for late May, 2012. This timing is expected to conflict with the busy season startup activities for growers, however, the period March through early May is necessary for organization and preparation of data. Cooperation with local conservation boards will be sought for this meeting with invitations sent to any party CPAC feels should be included.

(2) A final report describing the results for using TIM during the growing season will be written and provided by December 1, 2012.

(3) Progress reporting and generating interest in this technology are highly desirable and so, cooperation will be sought for publication of progress at about mid growing season in the local newspaper, the Valley Courier, as a press releases. Press releases will also be provided to the Valley Courier for the kickoff meeting, the results meeting and prior to the presentation to the 2013 Southern Rocky Mountain Agriculture Conference.

(4) A meeting to present the results of the study will be scheduled for November, 2012. As with the kickoff meeting, widespread participation will be sought.

(5) The Colorado Division of Water Resources and all regional conservation boards (especially RGWCD and Center CD) will be kept informed of this program because of the high potential this program represents to conserve water in SLV.

(6) Input will be sought from SLVRC and potentially contributing extension personnel.

(7) Presentations will be made to interested groups as the opportunities arise. Input from CPAC is requested to assist this effort.

8. Potential for results to leverage additional outside funding:

The Demo Farm will benefit from the telemetry and recording package established on the pivot. The instrument package will remain with the Demo Farm pivot to enable further testing and demonstration for future CPAC studies.

HydroBio is anticipating a USDA Small Business Innovative Research grant for TIM commercialization and has a Cooperative Research and Development Agreement (CRADA) with the USDA Agriculture Research Station in Bushland, Texas recognizing HydroBio's ownership of the TIM technology. A successful beta test of the program in the SLV dovetails nicely with the proposed SBIR research that already includes the RGWCD as a cooperator. Likewise, the SBIR provides a link between the profound water conservation efforts now underway in the Texas Panhandle and across the Ogallala aquifer. HydroBio is cooperating with the North Plains Groundwater Conservation District by providing TIM input for their 20012 200-12 program (growing 200 bu. of corn with only 12 inches of irrigation).

Other funding opportunities for related work are currently being explored, including Sustainable Agricultural Research Education, Natural Resource Conservation Service, USDA Agriculture Research Service, commercial center pivot manufacturers, pivot control/telemetry companies, and multinational water and energy corporations. HydroBio intends to bring synergy from other water conservation and TIM activities back to enhance water conservation in SLV.

9. Timeline and expected short term (1 year) and longer term (3-5 year) outcomes:

The short term goals of the project are to proof, enhance and demonstrate the conservation potential and certainty provided by TIM according to this timeline:

Task 1—Preparation: March and April, 2012. Data mining to understand power rates, irrigation practices, and growth curves and water use by potatoes, alfalfa and barley (using archived EOS and weather data) will be performed for calibration.

Task 2—Instrumentation: April and May, 2012. Collaborate with PTM, Agro Valley and Mr. Benton (Demo Farm) for placement of instrumentation and collection of field data.

Task 3—Outreach activities: Ongoing throughout the project. Newspaper and popular articles will be written, and presentations will to interested boards and groups will be made throughout summer, 2012 as opportunities become available.

Task 4—Track and prescribe irrigation: April through October, 2012. In collaboration with PTM, the results will be tracked online on the PTM website. This task will be conducted in collaboration with Agro,

Task 5—Establish irrigation rules and program them into TIM: July through August, 2012. This will be conducted in collaboration with Agro,

Task 6—Reporting: at the end of the growing season and be completed by December 1, 2012 . A presentation reporting the results will be made to the 201 Southern Rocky Mountain Agriculture Conference.

The long-term goals for this program are:

1. Develop potato, alfalfa and barley irrigation protocols within the TIM capability.
2. Demonstrate remote irrigation capability at the Demo Farm.
3. Position TIM for commercialization to serve the SLV growers, thereby changing irrigation for deep conservation.

10. Detailed Annual Budget

The annual budget for HydroBio's involvement provided in the table is $121,588. HydroBio proposes a 75 percent match for the study costs $91,191 that will be provided as in kind services. The full amount of the request for support from CPAC is 25 percent, or $30,397 for the entire year. This includes a one time outlay of $3,050 for equipment and a budget of $12,000 for EOS imagery. Both Agro and PTM have agreed to provide their services for this study gratis due to their interest in TIM—the value of their work is probably half again the total budget.

HydroBio Project Estimation

2012 -- SLV Targeted Irrigation Management														
PROJECT #: 2012-3 FILENAME:2012_CPAC.xls Labor (1)		Task 1. Preparation Data Mining Check Calibr.		Task 2. Instrument-ation and		Task 3. Outreach		Task 4. TIM Irrigation Prescriptions		Task 5. Program Irrigation Rules		Task 6. Reporting		Subtotals (across)
STAFF CATEGORY	**$/Hr**	**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Hrs**	**Dollars**	**Dollars**
Principal Investigator	$ 180	40	$ 7,200	12	$ 2,160	120	$ 21,600	40	$ 7,200	40	$ 7,200	80	$14,400	**$ 59,760**
Programmer	$ 125	10	$ 1,250	0	$ -	0	$ -	60	$ 7,500	60	$ 7,500		$ -	**$ 16,250**
Staff. Rem. Sens. Sci.	$ 95	120	$ 11,400	12	$ 1,140	20	$ 1,900	120	$11,400	8	$ 760	16	$ 1,520	**$ 28,120**
Labor Total:			**$ 19,850**		**$ 3,300**		**$ 23,500**		**$26,100**		**$15,460**		**$15,920**	**$104,130**
Expenses	Unit Cost	Units	Dollars	Units	Dollars(1)	Units	Dollars	Units	Dollars	Units	Dollars	Units	Dollars	Dollars
Travel Costs (RT SLV)	$ 200	1	$ 200	1	$ 200	3	$ 600	0	$ -	0	$ -	2	$ 400	**$ 1,400**
Per Diem (meals/day)	$ 46	2	$ 92	0	$ -	6	$ 276	0	$ -	0	$ -	0	$ -	**$ 368**
Nightly Lodging	$ 80	2	$ 160	0	$ -	6	$ 480	0	$ -	0	$ -	0	$ -	**$ 640**
EOS Imagery	$1,200							10	$12,000					**$ 12,000**
Equipment			$ -		$ 3,050		$ -	0	$ -		$ -	0	$ -	**$ 3,050**
Total Expenses			**$ 452**		**$ 3,250**		**$ 1,356**		**$12,000**		$ -		**$ 400**	**$ 17,458**
Total Labor and Expenses			**$ 20,302**		**$ 6,550**		**$ 24,856**		**$38,100**		**$15,460**		**$16,320**	**$121,588**
(1) Equipment includes a tipping bucket raingage ($200), telemetry from the flow meter($800), SW Solar sensor ($250) and AquaSpy rental and servicing for one year ($2000)													**Match by HydroBio**	**$ 91,191**
													Requested CPAC Support	**$ 30,397**