Application of the Precision Ag Irrigation Language (PAIL)

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Abstract: *Over the past six years, a team of industry professionals and Extension researchers has worked in the context of AgGateway's PAIL project to draft a standard for data exchange among irrigation technologies. This draft is currently in process to become an ASABE standard. The North Plains Groundwater Conservation District (NPGCD) has funded development of an integrated irrigation management system. The system is "integrated" in that it combines information from multiple irrigation technologies into a single web application. PAIL is the enabling element of this integrated system: each of the data sources (weather, soil moisture, and pivot control) exchanges information in the PAIL format. Development of NPGCD's system began in December of 2016 and is undergoing testing during the 2017 irrigation season. We present initial results from the development and application of the NPGCD's system and observations relating to how the PAIL standard reduced cost and complexity for the system's software.*

Keywords: PAIL, irrigation management, data exchange, standards, systems integration

Introduction

Irrigated agriculture in the US accounts for 80-90% of the consumptive water use and approximately 40% of the value of agricultural production (Schaible and Aillery, 2012; USDA, 2009). This value, totaling nearly $118 billion, is produced on 57 million acres. Given the increasing challenges in water availability and the likelihood of increased water conflicts from competing users, irrigated agriculture must increase its efficiency without sacrificing a reduction in the value it produces (Schaible and Aillery, 2012). Growers can derive much of this efficiency through application of precision irrigation technologies, and on-farm management systems that facilitate sound agricultural practices. However, less than 10% of irrigated farms use any advanced decision support tools or technologies (USDA, 2009). Improving adoption of these technologies is critical to increasing efficiency.

Recently, a group of companies, industry representatives, academics, and interested parties began collaborating to address the issue of systems integration in irrigation (Hillyer et al., 2014). This project, called **Precision Ag Irrigation Leadership** (PAIL), has the specific goal of producing a set of data exchange standards that enable development of more efficient and easier to use solutions for irrigation management. The PAIL participants represent a diverse group of technologies including companies producing Farm Management Information Systems, Pivot Irrigation Systems, weather and environmental monitoring equipment, and soil moisture monitoring equipment. By having a "common language" for data exchange, manufacturers can collect data from a variety of sources without the burden of developing specialized exchange methods for each different data source. The PAIL standard will improve interoperability of irrigation technologies and, consequently, increase adoption of more efficient irrigation practices.

Details of the purpose, scope, and structure of PAIL have been described elsewhere (Adhikari et al., 2016). In this paper, we present a demonstration project that applies the PAIL data standard. This project includes the development of a "fully integrated" irrigation scheduling program and an on-farm demonstration of the program.

The argument for PAIL

Consider a generic irrigation management tool that is intended for implementing Scientific Irrigation Scheduling (SIS). For this example, the “system” is a software system that is capable of working in most contexts and is generic in that it is not limited to a particular brand or type of hardware. Figure 1 shows how a software developer might view the system from a very simplified perspective. The system must have some sensors since physical measurements are the basis for SIS. Data from those sensors must move out of the field via some mechanism such as cellular or radio telecommunication. The system must store these data and perform analysis or calculations to produce irrigation recommendations. The bulk of the management system’s software resides in this storage & analysis component. The user is also an essential component of the system. Implementing SIS requires knowing how much water was applied. Typically, the user (i.e., the irrigator) must supply this information. Finally, the user is the recipient of any recommendations generated by the system.

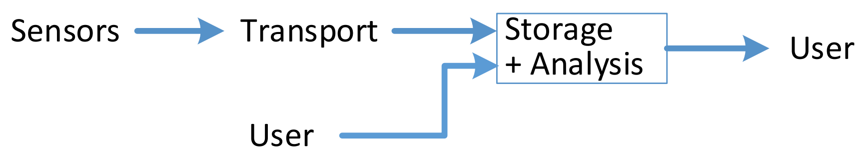

Figure 1

Since this system should be generic, the software developers cannot assume that the users have only one sensor type or brand. The three methods of SIS (soil moisture measurement, evapotranspiration, plant sensing) each use different kinds of sensor, and their data differs in structure, units, and meaning. Furthermore, we cannot assume that a particular user has only one brand of sensor. Figure 2 shows how the developer might view the system after taking into account that the grower might use many sensor manufacturers or sensor types might. Conversion components are required to move all those data into the analysis component, and the size of the analysis tool has grown accordingly.

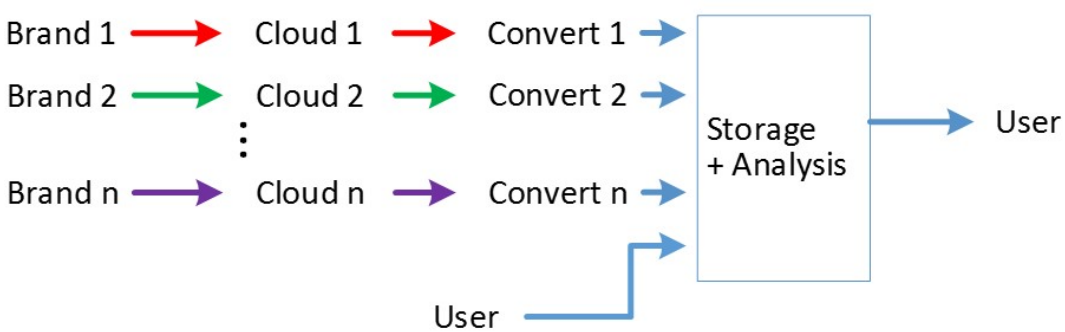

Figure 2

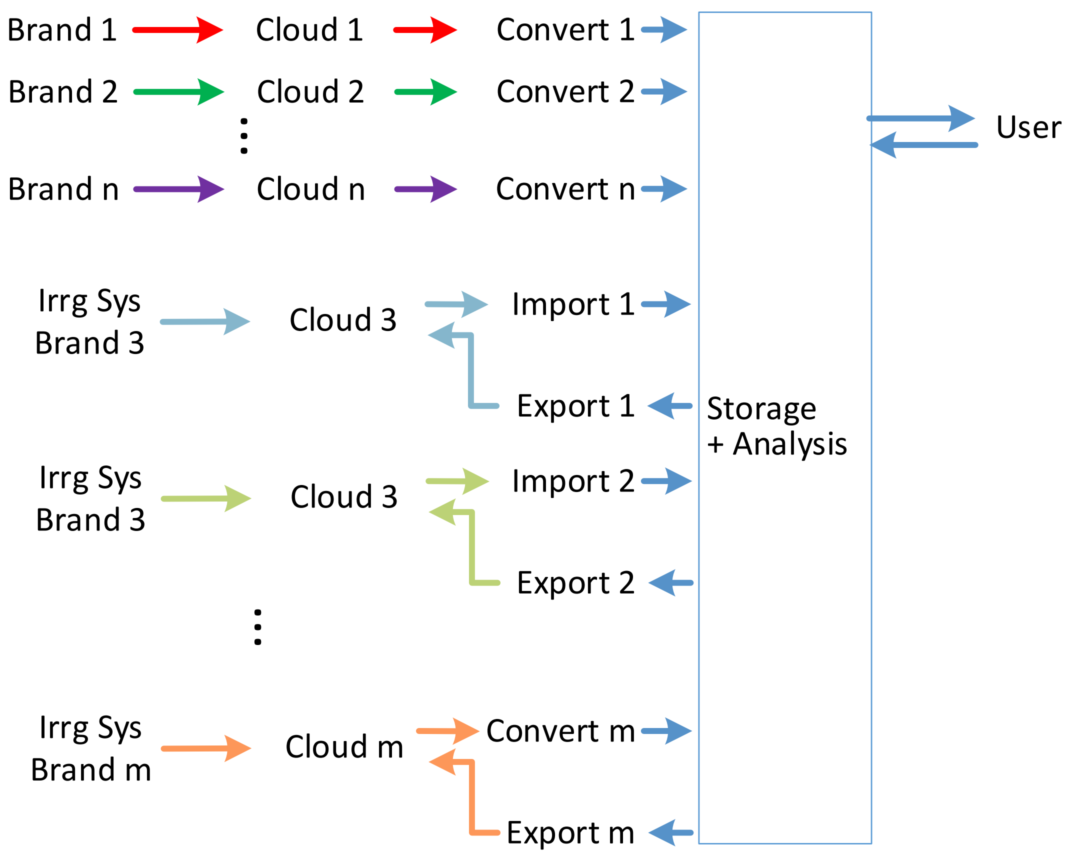

Figure 3

The multi-brand sensor view in Figure 2 still shows the user as the source of water application data. Relying on the grower for irrigation data is still a common design decision for scheduling tools and is an additional burden on the user. Most modern pivot control systems have some mechanism to export when and how much water was applied. A fully integrated irrigation management system could take advantage of this data stream and relieve the user of that burden. The obstacle to doing this integration is that each manufacturer uses their proprietary format for the irrigation records. Figure 3 shows how the developer might vie the fully integrated system. In this view, the user is no longer burdened with entering data. The burden has been moved to the software system and manifests as additional import/export/conversion code. Moving this burden to the software is undoubtedly a benefit to the user. However, the additional import/export/conversion are an added cost to development and are a disincentive to the development of generic an fully integrated SIS tools.

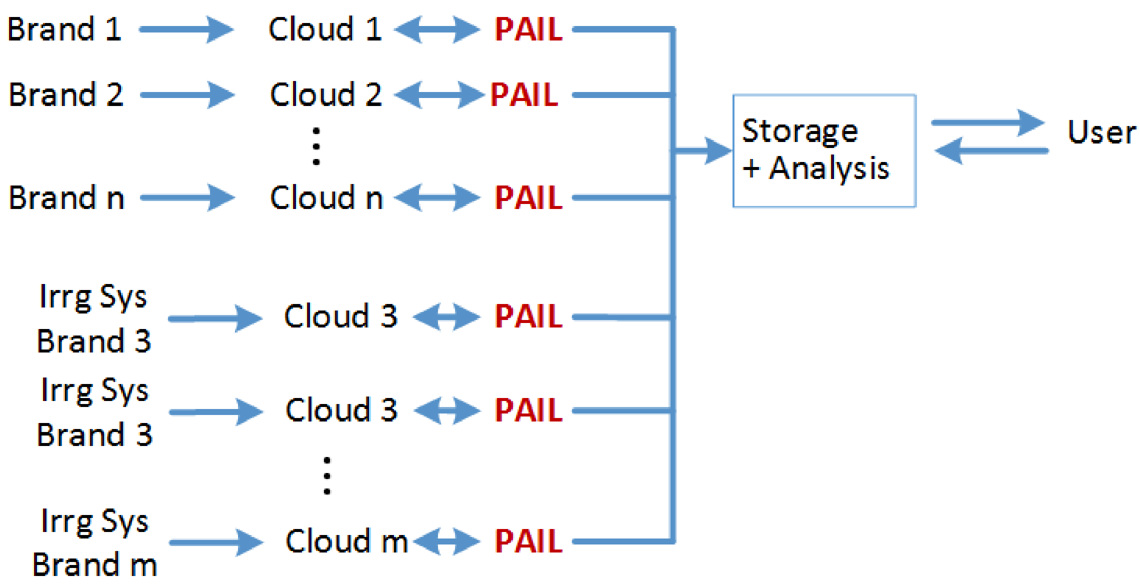

Figure 4

The PAIL standard proposes a single format for exchange of all the data relevant for irrigation management. Figure 4 shows a revised view of the system where PAIL is the only exchange format. In this case, the Storage & Analysis component is smaller because it no longer needs additional code to integrate a myriad of data sources.

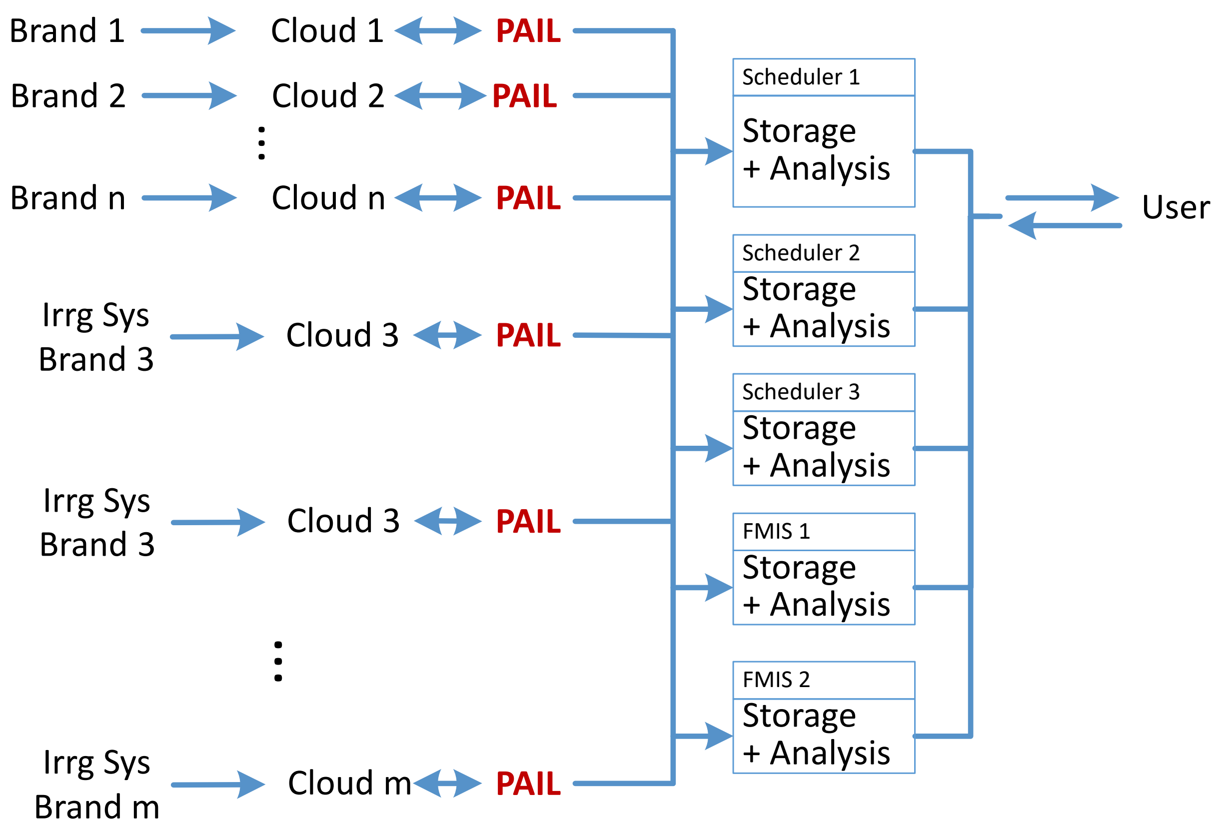

Figure 5

One could argue that PAIL is merely pushing the conversion problem back on the manufactures since they would need to implement the conversion code in their products. In fact, the manufacturers face a similar problem as the SIS system's software developer. Many software systems can derive value from sensor data or irrigation system records. Interoperating with each of these systems means the manufacturers face the same problem of converting to a myriad of formats. The PAIL standard has value for the manufacturer since they can build to a single format while still supporting multiple data consumers. Figure 5 illustrates how PAIL benefits both producers and consumers of irrigation data.

The preceding example embodies the basic argument for PAIL. Having a standard format for irrigation data exchange addresses problems for multiple actors in the irrigation space. From the grower's perspective, PAIL addresses the mixed fleet problem where the grower must integrate data from disparate sensing or control systems. From the manufacture's perspective, PAIL addresses the issues arising from having many different consumers of data each with different formatting requirements. In a general sense, PAIL addresses the issue of SIS adoption by making SIS system easier to build and easier to use.

North Plains Groundwater Conservation District's Irrigation Scheduling Tool

The issues discussed in the previous section are essentially a systems integration problem. Systems Integration (SI) has its origins in military programs (Hobday et al., 2005) and has steadily spread to nearly every business sector. Agriculture has been slow to receive the benefits of SI across many areas of the farm enterprise. This is particularly true in the irrigation sector, and the reasons for slow adoption are varied. Stafford (2000) [1] posited, "data-overload' for the manager has to be overcome by the development of data integration tools, expert systems, and decision support systems." A recent meeting of 44 representatives of the irrigation industry, extension, and academia examined the problems and issues surrounding the adoption of efficient irrigation practices (Two Valleys Roundtable Report, 2015). The group concluded that systems integration (or lack thereof) is one of the things the group cited as a barrier to adopting new technologies. A similar but smaller group of irrigation experts met to examine the future of irrigated agriculture (English, 2015). One of the group's specific recommendations to stimulate adoption of efficient irrigation practices is "making equipment vendors more aware of financial support programs, *management tools*, and outreach sources." The conclusions of these two groups indicate a clear need in the realm of irrigation management: producers need new tools, and the tools must integrate as much data as possible.

The North Plains Groundwater Conservation District (northplainsgcd.org) has endeavored to create a fully-integrated irrigation scheduling tool. This tool is funded by a grant from the Texas Water Development Board (twdb.texas.gov), and Texas A&M AgriLife Extension is building the system (agrilifeextension.tamu.edu). The software is based on the sIMO irrigation scheduling tool originally developed at Oregon State University through an Oregon NRCS CIG grant.

The primary objective of the NPGCD project is to produce an irrigation scheduling tool that is useful to producers in the Texas panhandle region. Growers in this region are progressive, early adopters of practical irrigation technology. Soil moisture probes and pivot controls with remote telemetry have been common in the region for many years. To support these growers, the system should have the following features:

1. The system should be as simple as possible while still implementing SIS.
2. The system should automate all data flows needed for data integration. The data flow is automated in that the user is not required to take any specific action to generate irrigation recommendations. For example, users will not need to manually download ET data or enter irrigation amounts.
3. The system should use a water balance based estimate of soil moisture. This requirement indirectly stipulates that evapotranspiration will drive irrigation decisions however soil moisture measurements will be used wherever possible.
4. The system should mitigate uncertainty associated with estimated soil moisture depletion or recommended irrigation amounts. T this end, the system uses NOAA FRET and QPF forecast products to produce a 7-day forecast of depletion. Additionally, the system includes a user direct correction algorithm to compensate for sensing errors or calibration issues

[1] While citing (Sigrimis et al., 1999)

5. The system will provide reporting features necessary to support the NRCS EQIP medium intensity IWM practice.

The secondary objective of this system is to demonstrate the use of the PAIL data standard in the context of an irrigation scheduling tool. To that end, the sIMO system was modified to accept PAIL formatted documents. These documents include both weather data (ET and precipitation) and water application data (irrigation dates & amounts). The software also generates irrigation recommendations in the PAIL format, but there is as yet no participating consumer for these records. Details of the structure and content of PAIL documents have been presented elsewhere (Adhikari et al., 2016). The goal of this demonstration is to promote adoption of the PAIL standard. The modified sIMO system will use most of the basic functionality supported by PAIL. Once the system is thoroughly tested, the source code will be released under an appropriate open source license.

System Structure

Figure 6 shows the packages that make up the modified sIMO system. The **ASP.NET Application** contains all the interface code. The sIMO tool is implemented as an ASP.NET web application written in C#. The **Database** is implemented in Microsoft SQL Server, and all the water balance and related calculations are implemented as stored procedures in T-SQL. Some of the API related code (i.e., downloads from NOAA NDFD) and the ASCE Standardized ET equations are implemented in C# as SQL CLR stored procedures. The **PAILlib** package contains a C# implementation of the PAIL object model. This package also contains necessary code to translate from PAIL constructs to sIMO database structure and vice versa. The "**Vendor Specific Adapter**" handles API calls and object translation for those vendors that do not fully support the PAIL standard. Some of the cooperating sites have hardware from vendors that are not participating in PAIL's development (see Table 1). This is treated as an opportunity to demonstrate translation from vendor-specific t formats to/from PAIL native documents. The vendor-specific nature of this code means that it will not be part of the open source version of sIMO unless the vendors explicitly agree to be included.

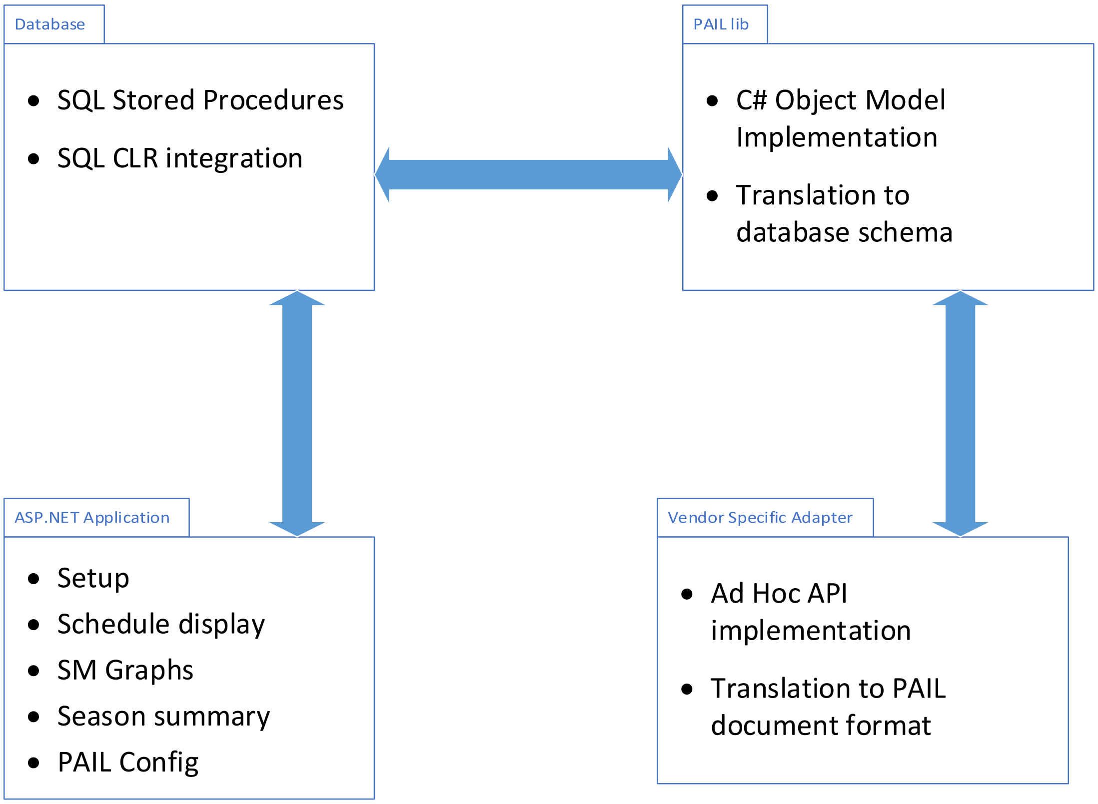

Figure 6

In Season Data Flow

Figure 7 shows a conceptual view of the data flows during the irrigation season. The two primary sources of data mirror the two main scope divisions in PAIL. For the demonstration, the field sensors are primarily weather stations. These stations meet the requirements of ASABE EP505 (American Society of Agricultural and Biological Engineers, 2015) and the stations provide either reference ET or the data needed to calculate ET. The operations side is focused on when and how much water was applied.

Some of the hardware uses cloud-based storage, and others use direct cellular connections. In either case, sIMO obtains the data via HTTP. There is no specific API stipulated by PAIL. Having no standard API means that sIMO must implement separate download code for each vendor. IN nearly all cases, the API code is simple because the PAIL document structure is robust enough to contain any variation that would otherwise require a more complex API interaction.

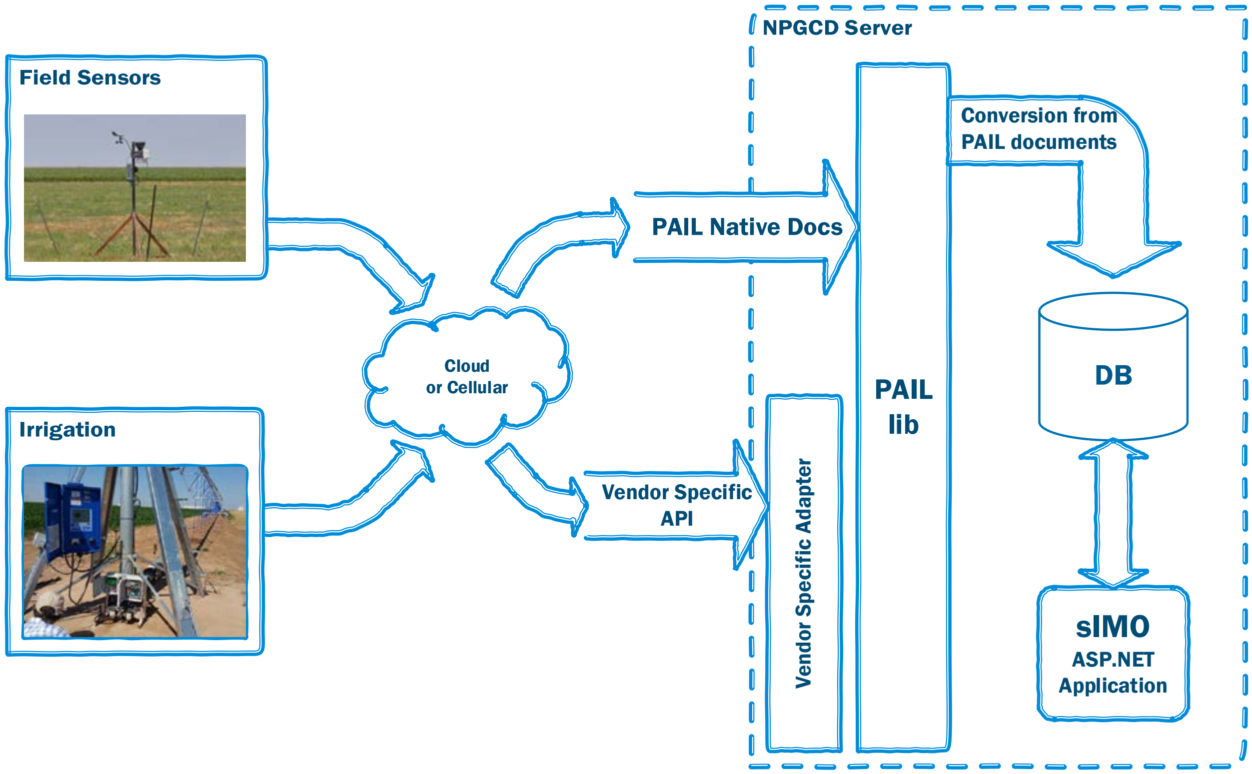

Figure 7

sIMO Interface

The original version of sIMO was constructed to be "as simple as possible." The system achieves this goal via three features: 1) only require information needed to calculate a simple water balance, 2) use mouse-based input for as much user interaction as possible (i.e., minimize typing), and 3) the smallest possible interface. The sIMO interface consists of four primary pages. Figures 8 – 11 show screenshots of each page.

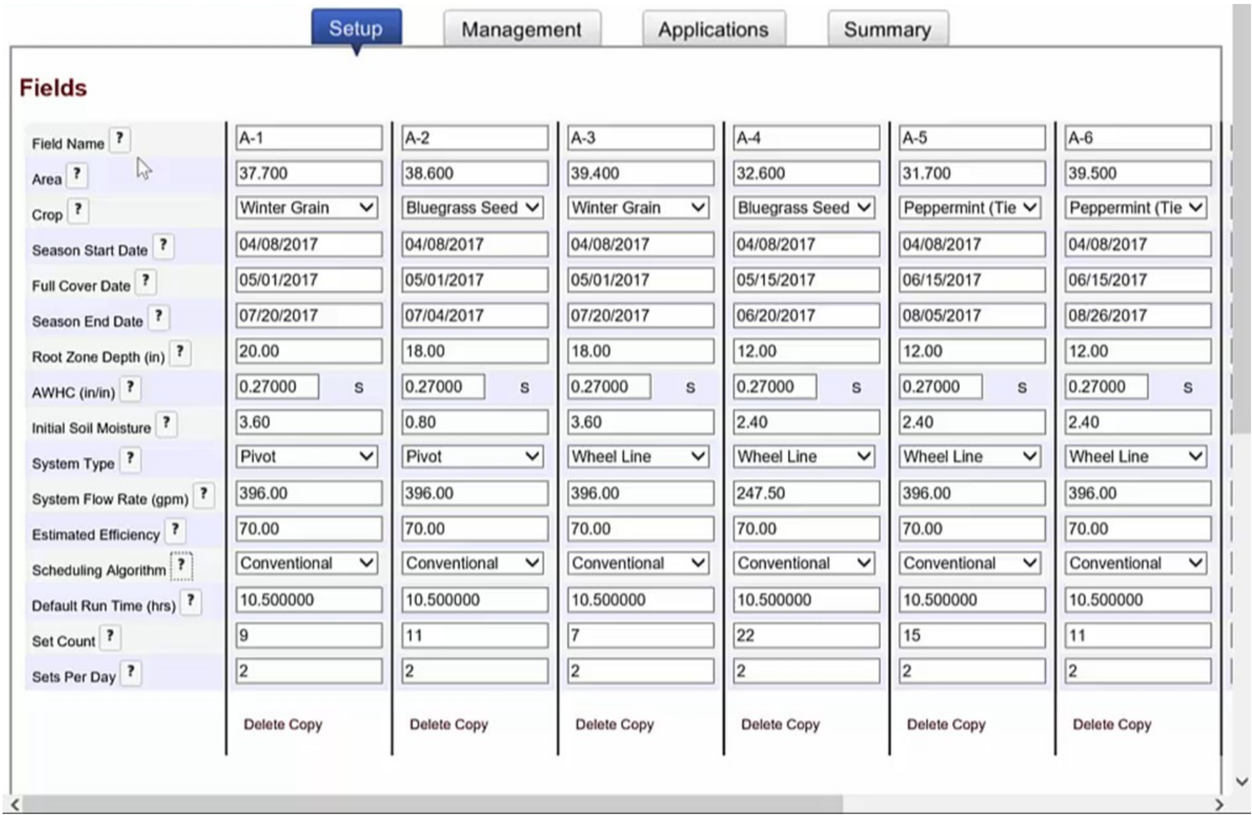

Figure 8. Setup Page

The Setup page contains all the field-specific information needed to set up the water balance calculations. sIMO presents the information in tabular (pseudo spreadsheet) format, and the user can employ a copy-paste procedure to set up multiple fields. The interface can also download estimated soil water holding capacity from the NRCS Web Soil Service if the user knows the name of the dominant soil. Basic farm-level setup information is also accessible on this page.

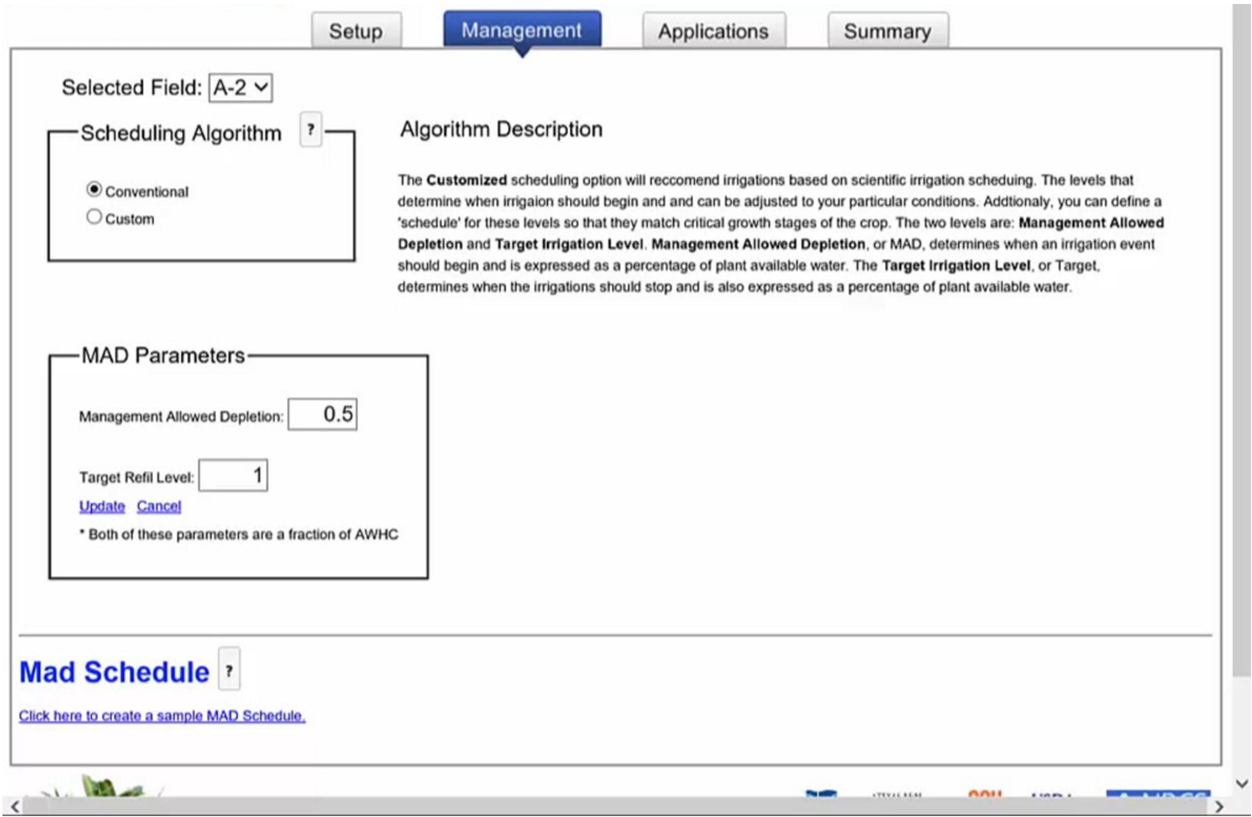

Figure 9. The Management page

The Management page is where the user specifies how the system should schedule irrigation. sIMO uses the MAD approach to schedule irrigation (Merriam, 1966). By default, the system uses a MAD of 50% and the system calculates runtimes to refill the soil profile to field capacity. More advanced options enable specific values of MAD and target refill level, including a schedule of MAD & Target levels that change during the season.

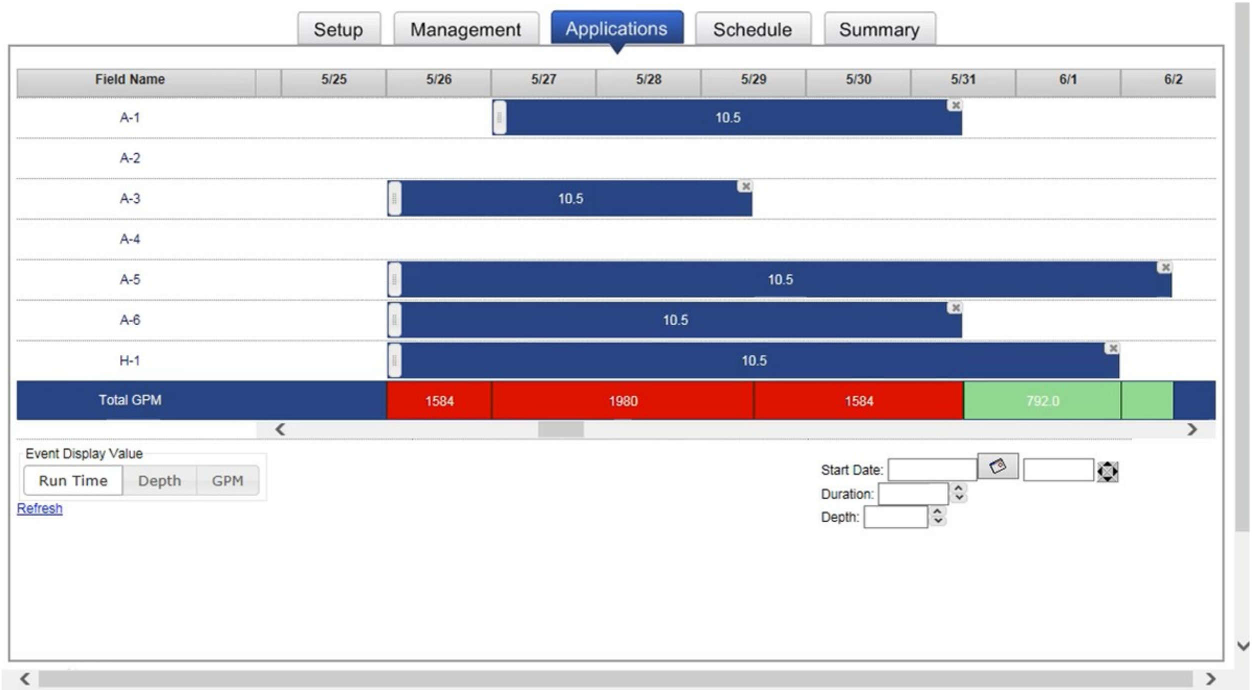

Figure 10. The Schedule page

The Schedule page is where the user can see both past irrigation and a recommended schedule for the next 7 days. The interface is a modified Gantt chart where each swim lane represents a single field. The blue bars represent individual irrigation events. The user can click and drag the event to change the start date or duration or double click to create a new event. Clicking on the row causes it to expand and expose a spreadsheet-like interface that shows each of the water balance components for each day. All of the water balance components are editable via spinners.

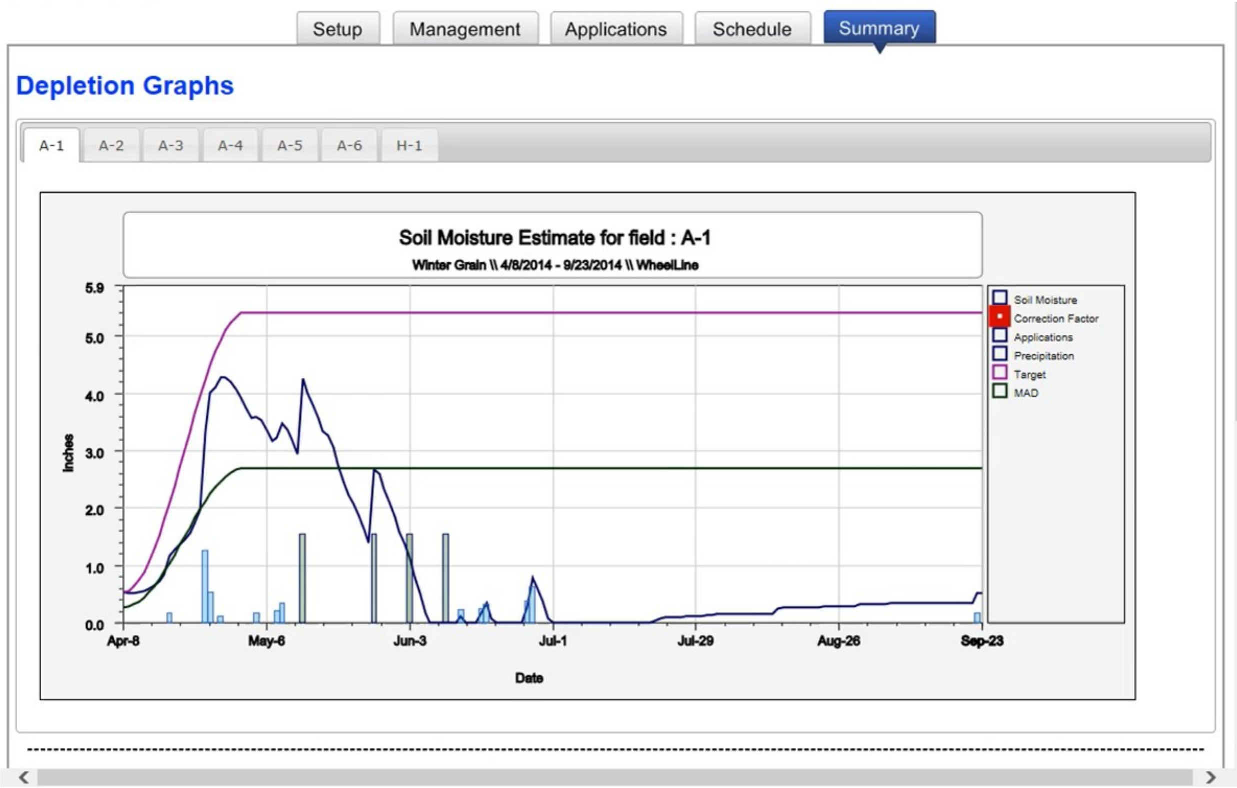

Figure 11. The Summary page

The Summary page shows graphs of depletion for the whole season. These are the typical plots soil moisture plots that show available moisture (blue line), irrigation (blue bar), precipitation (grey bar), and management limitations (green/purple lines). This page also has a table of season totals for each field and an option to download the water balance calculation as a CSV file.

Demonstration Status

A significant component of the NPGCD project involves an on-farm demonstration of the scheduling system. Five sites were selected for the demonstration in 2017. Table 1 summarizes the data sources at each site. The focus during 2017 was on development and testing, so no active scheduling occurred during this season. The demonstration will continue during the 2018 season.

Table 1 2017 sIMO test sites

Site	**Field Sensors**	**Irrigation System**
NPGCD 1 (Etter)	Campbell Scientific (PAIL)	PivoTrac (PAIL adapter)
NPGCD 2 (Etter)	Campbell Scientific (PAIL)	Lindsay (PAIL)
Cooperator 1 (Dumas)	Ranch Systems (PAIL adapter)	PivoTrac (PAIL adapter)
Cooperator 2 (Texline)	ZedX (PAIL)	PivoTrac (PAIL adapter)
AgriLife (Bushland, observe only)	ZedX (PAIL)	AgSense (PAIL)

Figure 12. Weather station installation at Cooperator #1

Conclusion

This paper described an ongoing effort to build a fully-integrated irrigation scheduling tool, sIMO. The management system is designed to be fully integrated so that it can accept data from both field sensors and irrigation control systems and will generate irrigation recommendations in the PAIL standard format. The level and scope of integration are made possible by the PAIL data exchange standard.

Preliminary testing of the system occurred during 2017 and will continue during 2018. We will release an open source version of the scheduling tool after the 2018 irrigation season.

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