Precision Ag Irrigation Language (PAIL) Project

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Abstract. Agriculture is entering the era of "big data" which will be the basis for evidence-based management in precision agriculture. The collection, storage, and streaming of big data requires technical tools that must be integrated into a farm enterprise. However, these tools are incompatible with each other due to different designs, data formats, and transfer protocols. Furthermore, data delivered by a tool represents only one part of a set of information required by a grower to make a management decision. Growers have been reluctant to adopt these tools because of their incompatibility in design and their inability to be integrated into a holistic solution for decision making. Only through the implementation of data exchange standards will these disparate tools be adopted by growers and their supporting cast in the agricultural industry.

The Precision Ag Irrigation Language (PAIL) project is part of an industry-wide effort under the AgGateway business consortium to create open data exchange standards for agriculture. The focus of the PAIL project is on irrigation data exchange standards. PAIL is a collaborative effort of 20+ companies; it was chartered by AgGateway's Precision Agriculture Council in 2013 following preliminary work organized by the Northwest Energy Efficiency Alliance (NEEA). The PAIL team is nearing submission of a draft open standard to ASABE with the goal of it becoming an international standard in ISO. This paper describes the PAIL project, including its scope and primary deliverables (process models, Core Documents, and data exchange schemas for Core, Operations, and Observations). It discusses how these deliverables can be used in a farm enterprise.

Keywords. information management. irrigation. irrigation technology. precision irrigation. standards.

Introduction

The United Nation's Food and Agriculture Organization (FAO) has projected the earth's population will exceed 9 billion by 2050 (Alexandratos and Bruinsma, 2012). This increase will require an additional billion tons of cereal produce alone; nearly a 33% increase over current levels. The FAO expects most of the gains to come from increased yield and increased land in production. However, in developed countries, where FAO projects an 8% decrease in land for production, cereal gains must come from an increase in yield. Even with the 33% increase in production, the FAO believes that water demand will increase by only 11%. The reduced rate of increase is expected to come from improvements in water use efficiency and a reduction in rice production. Most of the increase in efficiency will come from improvements in stress tolerance and reduced water needs in new varieties (Baulcombe, 2010). In developed nations, some of the increase in water use efficiency will be from improved management practices. Regardless of the projections, farmers in the future will be pressured to increase production on less land and with reduce water use due to competition with other sectors in society.

It is not necessary to look beyond the United States to find evidence of pressure on irrigated farms. Irrigated agriculture in the United States (U.S.) accounts for 80-90% of the consumptive water use and approximately 40% of the value of agricultural production (Schaible and Aillery, 2012). This value, totaling nearly $118 billion US dollars, is produced on 57 million acres. According to the most recent Farm and Ranch Irrigation Survey (USDA, 2012) , 25,853 out of 296,303 irrigated farms reported reduction in yields due to a shortage of ground or surface water. This reduction is in addition to yield losses due to 6,011 farms discontinuing irrigation. The number of farms discontinuing irrigation is up more than 30% from the last survey.

The need for a standard

Agriculture has become a data-driven endeavor. New sources of information about soil, weather, crop status, machine operation, marketing, and economics all facilitate the evidence-based decision-making that defines precision agriculture. Using these new data streams requires tools and the evidence of this is found in the proliferation of new applications (apps) for mobile devices. A search of the Google Play store for the words "Agriculture" or "irrigation" yields 92 and 82 results, respectively. Even though these apps improve accessibility to data, growers are still responsible for relating the data to decisions in a farm enterprise. Furthermore, accessed data can be from diverse sources representing different scales, formats, and units. Consequently, the exercise of relating data can involve one or more tasks, such as combining data from multiple sources into a single output; performing calculations that transform data into specific recommendations; or using data as input into models to predict some potential outcome. Each of these tasks requires moving and transforming data. Tasks working together can be considered integration. The integration produces decision-making power that is greater than the sum of the individual tasks and data streams. It provides the evidence needed for evidence-based management.

There are many approaches for managing irrigation as shown in Figure 1, which is Table 22 of "Methods used in Deciding When to Irrigate" section of the Farm and Ranch Irrigation Survey (USDA, 2012). As can be seen in the figure, most approaches do not utilize technical tools, which are necessary for evidence-based management. In fact, technical tools, such as an irrigation schedule resulting from a computer simulation model, represent only 64,037 out of 369,917 approaches. This imbalance in favor of non-technical approaches has persisted over the last seven surveys dating back to 1988. (Smith et al., 2010)

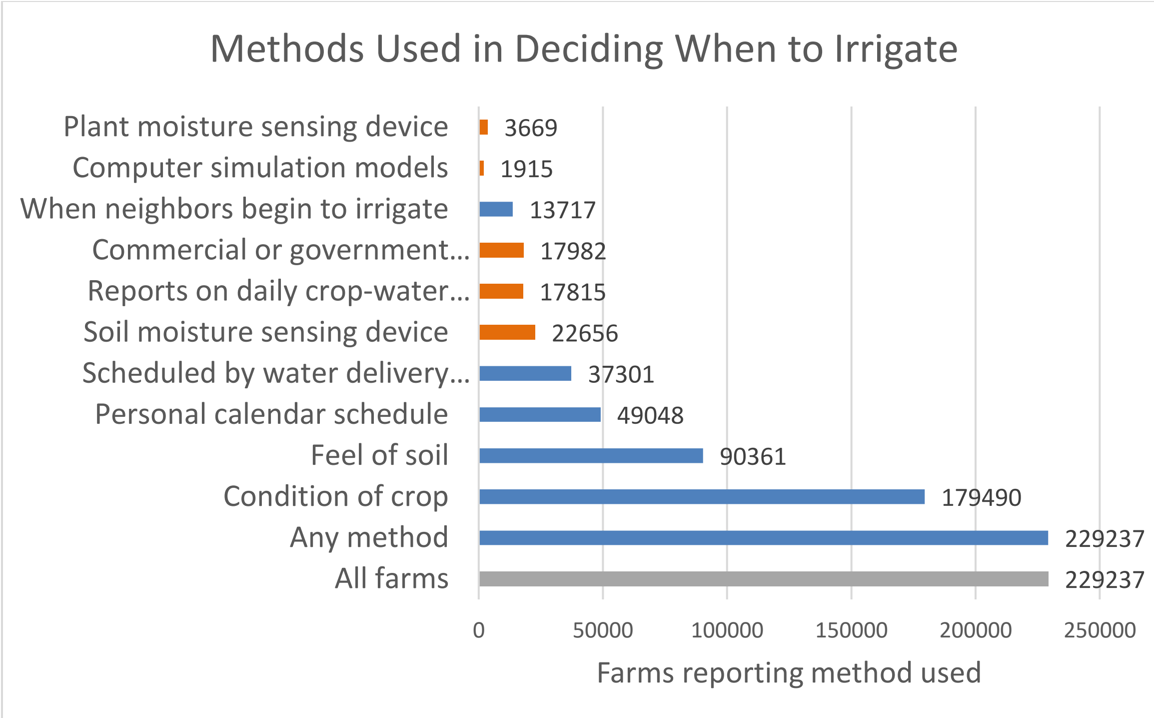

Figure 1. Table 22, Farm and Ranch Irrigation Survey, 2013 Census of Agriculture.

There are several potential explanations for the poor adoption of technical tools. First, there may be no incentive to change if things are working, even if there is an unforeseen benefit. Second, it takes more effort to install and maintain a soil moisture sensor than to just "feel the soil." Third, a technical tool may only provide some of the data or information to support a decision. For example, when maximizing the value of water, a soil moisture sensor only tells part of the story. Growers also need to know how much water was applied, how much the crop has used, what the weather has done, and the condition of the crop. Sensors exist for each of these information sources, but only as separate tools. Maximizing the value of water requires integrating all these tools. Therein lies the problem, the tools do not communicate to each other and as such they are not Integrated. The integration of tools is currently the responsibility of a grower, who may or may not have the know-how, people, funds, or time to do it. No matter the reason, the effort required can be discouraging.

Farm Management Information Systems (FMIS) are an obvious point of integration for technical tools. By facilitating integration, an FMIS alleviates some of the grower's burden. Implementing this integration requires an FMIS to have special code to interoperate between tools, and ultimately between sources of data. As new tools emerge, an FMIS must continue to expand. If each of the different tools could produce data in the same format, integration would be simpler and cheaper. A common data format would not only facilitate integration, but likely lead to a proliferation of new and more comprehensive FMIS solutions. This proliferation would in turn lead to increased adoption of more efficient technical approaches for deciding when to irrigate.

The multitude of technical tools to mine new data sources, the availability of cheaper telemetry, and the expanding role of FMIS all portend an important opportunity to improve irrigation management. However, there is no established framework for integrating these disparate tools and incorporating telemetry. This lack of a framework creates an immediate need for an irrigation-related, data exchange standard. Without a standard for data exchange, irrigation will miss the "Big Data" revolution and will instead remain a "manual" management activity as evidenced by the choice of approaches shown in Figure **1**.

The PAIL Project

In 2011, a group of companies, representing the irrigation segment of agriculture, was brought together by the Northwestern Energy Efficiency Alliance (NEEA) to explore the development of data exchange standards for irrigation. In late 2013, the development effort was moved into AgGateway (www.aggateway.org), a nonprofit consortium of about 240 companies dedicated to the implementation of standards for Agriculture. This move led to the chartering of the PAIL project by AgGateway's Precision Agriculture Council in early 2014. The companies participating in the project became known as the PAIL team.

The goal of the PAIL project is to develop industry-wide standards that will enable the exchange and use of data from different irrigation management systems. Data are currently stored in a variety of proprietary formats and each company is responsible to bear the cost and effort for making an exchange. The PAIL project seeks to develop a common language that can enable data exchange and, in the process, begin addressing the integration of technical tools for evidence-based, irrigation management.

The PAIL project covers a wide range of data topics, which can be organized into two broad categories: operations and observations.

- **Observations** are the field, atmospheric, plant, or other in situ measurements that apply to irrigation management. Data collection tools include weather stations, soil moisture sensors, or crop-related sensing. This work is based on, and extends, the ISO19156 standard for observations and measurements (International Organization for Standardization, 2011).
- **Operations** are all activities associated with the application of water with an irrigation system. Activities include, but are not restricted to, management-level communications and record-keeping. The operations data set is based around a "Recommendation", which describes a suggested course of action; a "Work Order," which describes a desired course of action; and a "Work Record," which describes the action that occurred. This work is based on, and extends, the ISO11783-10 standard for communications between agricultural machinery and FMIS (International Organization for Standardization, 2015).

There are several deliverables that will come from the PAIL project. Of those, five are important for this paper.

- **User Stories** (Jeffries, 2001) and Use Cases (Jacobson, 1992) that describe, in a semi-structured way, the typical management scenarios involving the exchange of data. User stories and use cases effectively define the scope of the standard.
- **Process Models / BPMN Diagram**s (von Rosing et al., 2015) that represent the different processes performed by actors in irrigation field operations. Explaining Business Process Modeling Notation (BPMN) is beyond the scope of this paper, but there are two aspects relevant to PAIL. The first is that BPMNs are based on a business process, that is, the management process as seen from the perspective of a farmer, whose goal is to operate as a profitable enterprise. The second element is that the process of building the BPMN results in identification of a set of messages (and data thereof) that define the communications that occur during irrigation management.
- **A field trial** (or "beta-test") that serves to expose potential conflicts or shortcomings of the standard. The trial also serves as a demonstration of the standard's value to potential adopters. The PAIL team conducted a trial during 2015 and is performing a second in 2016.
- **The XML Schema** (Fallside and Walmsley, 2004) is the primary technical deliverable. The schema contains a structured and unambiguous definition of data and its format.
- **A U.S. National Standard**, submitted to ASABE. A standards project, X632, is already in progress in the ASABE irrigation management committee, NRES-244. Drafting of this standard is underway and submission for balloting is expected in late 2016. This ASABE standard will subsequently be submitted to the International Organization for Standardization (ISO) as a new work item proposal.

Design Goals

The PAIL team applied several guiding principles during the design of a data exchange standard. These principles reflected the needs of individual companies in PAIL and project goals as a whole. At each point during the development process, where critical design decisions emerged and multiple solutions were available, the design principles guided the team's decisions. The principles were not set in stone from the start of the project. Instead, they emerged as each member contributed to the development and expressed their individual needs. Each guiding principle is described below.

Simple Beats Clever
On the surface this may seem like a different flavor of "KISS," but the intention is subtle. When formatting data, it is often possible to express the same thing in multiple ways. Some ways may be more practical for one domain than another. There is a temptation to find a clever way to include both ways in the same data format. However, having more than one way to express the same thing creates added burden for consumers of data. Wherever possible, PAIL chose simple solutions over those that are ingeniously comprehensive.

Small Packets
Data relevant to irrigation move through a variety of transport systems. Cell modem, sat-phone modem, mesh network radios, spread spectrum, radios, and direct machine-to-machine communications are all relevant. Some of these mediums (e.g. machine-to-machine via internet) have robust bandwidth capability, but many do not (e.g. sat-phone service billed by the byte). The low-bandwidth systems are just as important as the high-bandwidth, so the PAIL standard must be suitable for bandwidth-constrained applications. To that end, the schemas strive to minimize the size of the data packets to the greatest extent possible.

Make It Useful for Consumers of Data
It is often convenient for producers of data to send "everything" to data consumers, especially if data is sent electronically over the Internet. However, the consumers can be overwhelmed and miss key data they need, or spend unnecessary time looking for it. When transferring data to a consumer, the producer should include only reference data that is necessary for a consumer to complete a desired transaction.

JSON Friendly
The PAIL schemas are expressed as XML Schema Definition documents. This implies that all PAIL documents will be XML documents. However, while XML is a mature language, it is not the only document formatting language available. RESTful APIs have become the mechanism of choice for many web-based platforms. XML and JSON are, in general, compatible formats. However, there are some ambiguities regarding how to interpret certain XML schema structures into JSON. AgGateway has established some guidelines to prevent these ambiguities when translating XML to JSON. PAIL has followed these guidelines wherever possible.

Use Compound Identifiers
The Compound Identifier is a construct originally developed in AgGateway's ADAPT group (AgGateway, 2016). These objects provide a locally-scoped unique identifier that enables the use of objects by reference. More detail on compound identifiers is provided in the Identity section below.

Paper Overview

In this paper, we present the core elements of the PAIL project, the business processes those elements were derived from, and an introduction to the data structures defined in the standard. The intended audience is both engineering research professionals who will review the standard, and practitioners who will ultimately implement the standard. This paper will enable interested persons to decide if the PAIL standard can help their organizations serve the irrigation industry and, ultimately, the irrigators themselves.

Actors, User Stories, and Core Documents

Development of the PAIL data standards began by eliciting knowledge about the needs of various "actors" in irrigation: growers, their farm staff, consultants, and service providers. The PAIL team initially represented the various actors' needs and perspectives using "user stories" (Jeffries, 2001). The team also represented the data they record and exchange during irrigation operations through a set of "core documents."

Actors

The planning, executing and recording of irrigation events typically involve several people. Of course, an individual can assume multiple responsibilities, so the actors are best seen as *persons* occupying one or more *roles*. The PAIL standard identifies these actors in Table **1** below.

Table 1. Actors in the PAIL Data Flow

Actor	Description
Grower	Has authority to make decisions for all aspects of the farm. Develops a *Crop Plan* (core document) to convey what crops will be grown, and when, on which fields. Creates *Work Orders* (core documents) out of *Recommendations* (core documents) received from the Consultant.
Consultant	Has expertise to recommend how fields should be irrigated throughout the growing season, or over multiple seasons. Reviews the Grower's *Crop Plan*. Uses data from field equipment, such as soil sensors and field weather stations, to support the recommendation process. Requests and receives data from offsite Data Providers. Integrates all relevant data to create an irrigation *Recommendation* (core document) for the Grower.
Irrigator	Performs tasks related to irrigating one or more fields; i.e., performs the actual irrigation field operation. Uses a *Work Order* (core document) received from the Grower or Consultant to initiate, run, and end an irrigation operation. May make a preemptive change in a work order; for example, if a rain event occurs the irrigator may suspend or halt an irrigation operation.
Data Provider	Collects, stores and makes available various forms of *Observations and Measurements* (O&M, core document) data. Collects and stores proprietary irrigation operation event data. Derives *Work Records* (core documents) from the irrigation operations event data, and makes them available to the Grower Note: The tasks described above could be performed by more than one Data Provider. For example, the irrigation operations data could be handled by one provider, the weather data sourced by another, and the soil water data by yet another.

User Stories

User stories provide the PAIL team a high-level set of development requirements.

Table 2. PAIL User stories

Phase	As a/an	I want to …	So that I can …
Planning	Grower	create a Crop Plan.	communicate my intentions for one or more growing seasons.
	Consultant	review the Crop Plan to know what crops will be planted and how they will be grown.	make irrigation recommendations based on the grower's goals.
	Consultant	retrieve soil moisture, field weather and other field scouting data.	integrate it into my data analysis and recommendation to the grower.
	Data Provider	retrieve, store and organize field, weather and other relevant data.	send requested data to an authorized user.
	Consultant	retrieve derived weather data from a weather data service provider.	integrate it into my data analysis and recommendation to the grower.
	Consultant	create a Recommendation.	can advise the grower with a seasonal irrigation work plan.
	Grower	review the Recommendation from my consultant.	ensure it is consistent with my farm practices and current conditions.
Execution	Grower	create an irrigation Work Order.	be sure the Irrigator knows how much water to apply and where to apply it.

	Irrigator	use the irrigation Work Order to send a command to the irrigation system controller.	begin and end the irrigation as planned, or modify as field conditions change.
	Data Provider	store a Work Record of what happened during an irrigation event.	provide a record as requested from an authorized user.
Reporting	Consultant	retrieve a Work Record of an irrigation event.	use the data as input for the next irrigation Recommendation.
	Grower	store and retrieve a Work Record.	use it as input for planning next season's crops and field operations, and provide reports, as necessary, to regulators and/or insurance providers.

AgGateway's Core Documents for Field Operations

Growers currently face increasing pressure to document their field operations (e.g., irrigation, crop nutrition, crop protection), both for regulatory and commercial reasons. AgGateway's Core Documents for Field Operations support these activities and provide a common set of communications among Growers, Irrigators, Consultants, and Data Providers. In summary, the grower plans how to grow a crop, and then enters a cycle where observations and measurements are made about the state of the crop, an expert recommends a course of action, the grower (or an agent thereof) decide what course of action to take, the action is taken, the results are recorded, and the cycle begins anew. A grower may have a similar interest for the purposes of establishing production costs and the cost-effectiveness of specific agricultural practices.

More formally, the Core Documents (enumerated in Table 3) define data that can be exchanged during specific processes associated with a field operation. The definitions are quite flexible because of the myriad of ways growers implement their record-keeping in response to regionally-specific regulatory requirements, market characteristics or farming operations, and personal preference.

Table 3. Core Documents

Document Name	Abbr.	Type	What It Conveys	Actor Involved
Crop Plan	Plan	Strategic	A high-level document describing how a crop will be grown on a given piece of land during a crop season. “This is how we’re going to grow this crop this season.”	Grower, or other actor involved in the strategic planning for the field operations.
Observations and Measurements	O&M	Tactical/ Predictive	A document containing data measured/observed in the field. “This is what’s happening (or what we think might happen) in the field.”	Crop scout, remote observation or a person tasked with monitoring conditions in the field.
Recommendation	REC	Tactical	"This is what I recommend we should do" This document is not always acted upon; it is acted upon via a work order, upon approval.	An individual, such as a consultant or agronomist, with the expertise / licensing necessary to recommend a course of action.
Work Order	WO	Tactical	"This is what we are going to do."	An individual with authority to order the work done.

Work Record	WR	Tactical/ Historical	"This is what we actually did in the field."	May be automatically generated; otherwise, an operator that performed the task.
Supporting Documents				
Reference Data and Setup File		All	"This is the common information we need to set up and support accurate and efficient data exchange."	Grower, or other actor involved in managing the grower's production data.

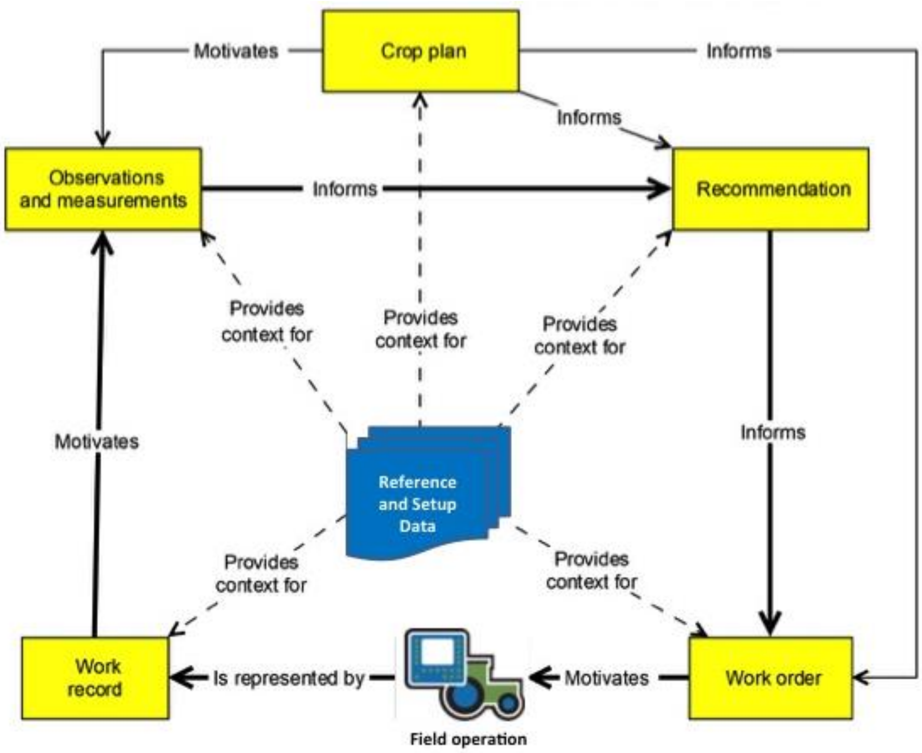

Figure 2. AgGateway Core Documents for Field Operations. The diagram in Figure 2 shows the relationships among the core documents.

- The Crop Plan informs or motivates the other documents.
    - Example: a crop plan defines an irrigation water quota available to a given field; this quota informs the Recommendation of whether to irrigate or not on a given day.
- Observations and Measurements inform Recommendations.
    - Example: soil water content measurements indicating the need to irrigate.
- Recommendations inform Work Orders.
    - Example: a consultant recommends irrigating because a corn crop's anthesis will happen soon.
- Work Orders motivate Field Operations.
    - Example: A grower purchases crop protection products from a retailer and requests their application.
    - Example: A grower communicates to an operator (irrigator actor) that a field must be irrigated with a certain depth of water over a certain period.
- Field operations are represented by Work Records.
    - Example: A telemetry system installed on a center pivot summarizes and reports data about the application of water on the field on a given day.
- Work Records motivate Observations and Measurements.

- Example: A crop scout goes out to the field to determine whether there are still symptoms of water stress in a crop following an irrigation operation.

Core Documents Flow

The previous section described the Core Documents and the relationships among them. In this section, an example is provided of the exchange of core documents as part of a Grower's business processes (Figure 3).

- The Grower shares the Crop Plan with an Agronomist and an Irrigation (O&M) service.
- The Grower shares a historical record of Work Records and O&M with the Agronomist.
- The Agronomist makes a recommendation ("Irrigation Plan") informed by the Crop Plan, the historical record, and fresh O&M.
- The Grower, informed by the Recommendation, orders a course of action through a work order ("Irrigation prescription") sent to the pivot panel, which executes the field operation.
- The Work Record ("Irrigation record") is returned to the grower (e.g. through a web service associated with the pivot's telemetry system.)
- The Grower processes the Work Record, creating a report shared with a regulator or value partner (e.g. a banker).

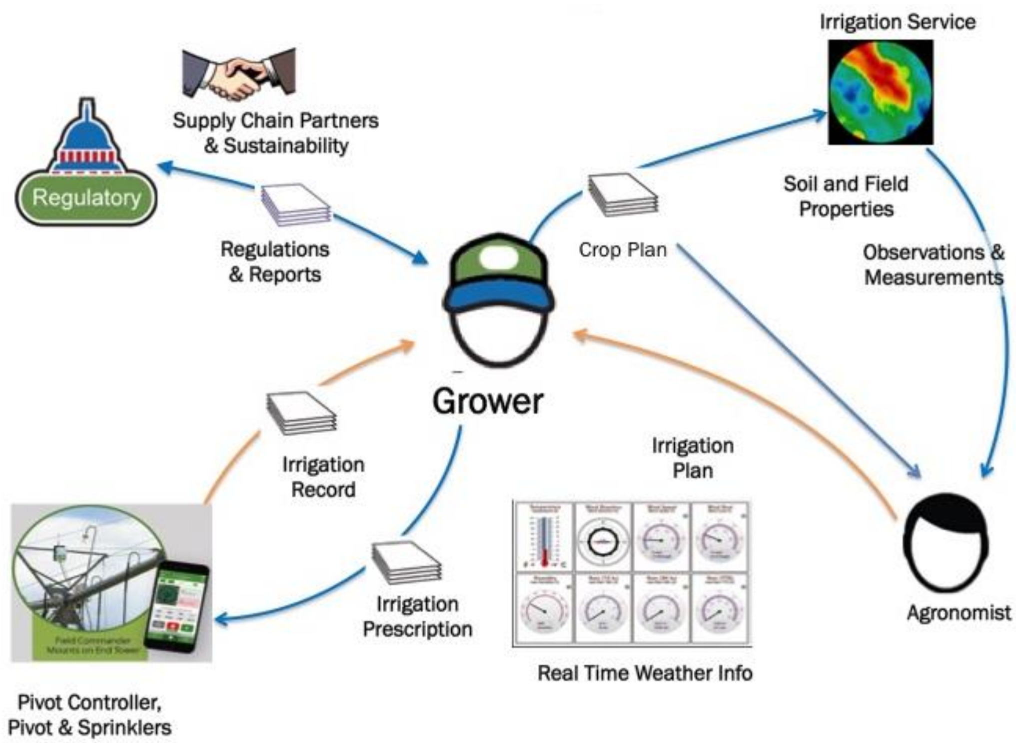

Figure 3. An example of the Exchange of Core Documents as part of a Grower's business processes.

Business Process Models

Figures 4 and 5 formalize the ideas shown above, bringing actors, Core Documents and relationships together in the context of formal processes. For clarity, Operations (Creation of Work Orders and Work Records) have been placed in Figure 4, and Observations (Procurement and use of O&M, Creation of Recommendations) have been placed in Figure 5.

As mentioned earlier, a detailed description of BPMN is out of the scope for this paper. A quick introduction supported by the key in Figure 7 should be sufficient to understand the following diagrams.

Different actors are represented by the rectangular horizontal *pools* in the diagram.

- The processes carried out by each actor are contained in the corresponding actor's pool.
- Processes begin, end, and sometimes are paused by *events*, shown as circles in the diagrams.
- There are different kinds of events, triggered by time (shown with a clock-face icon), receiving a *message* (shown with an envelope icon), or by a *rule* being met.
- Communication among pools happens through *messages*. Note that some of those messages correspond to Core Documents.
- The flow of a process can fork, depending on the outcome of an activity. The places where flow diverges (and converges) is shown with *gateways* (diamond shapes). The PAIL diagrams of Figures 5 and 6 only show a kind of gateway called "Exclusive-OR", where the divergent outcomes are mutually exclusive (i.e. only one outcome is possible in any given situation).

Figure 5 shows five different processes involved in irrigation operations.

- Grower creating a work order (from a received Recommendation) and sending it to the Irrigator.
- Grower requesting work records from a Data Provider and storing them in an FMIS.
- Irrigator executing a Work Order received from the Grower.
- Data Provider storing event data received during the execution of the field operation.
- Data Provider assembling work records from stored event data, and sending them to the Grower upon request.

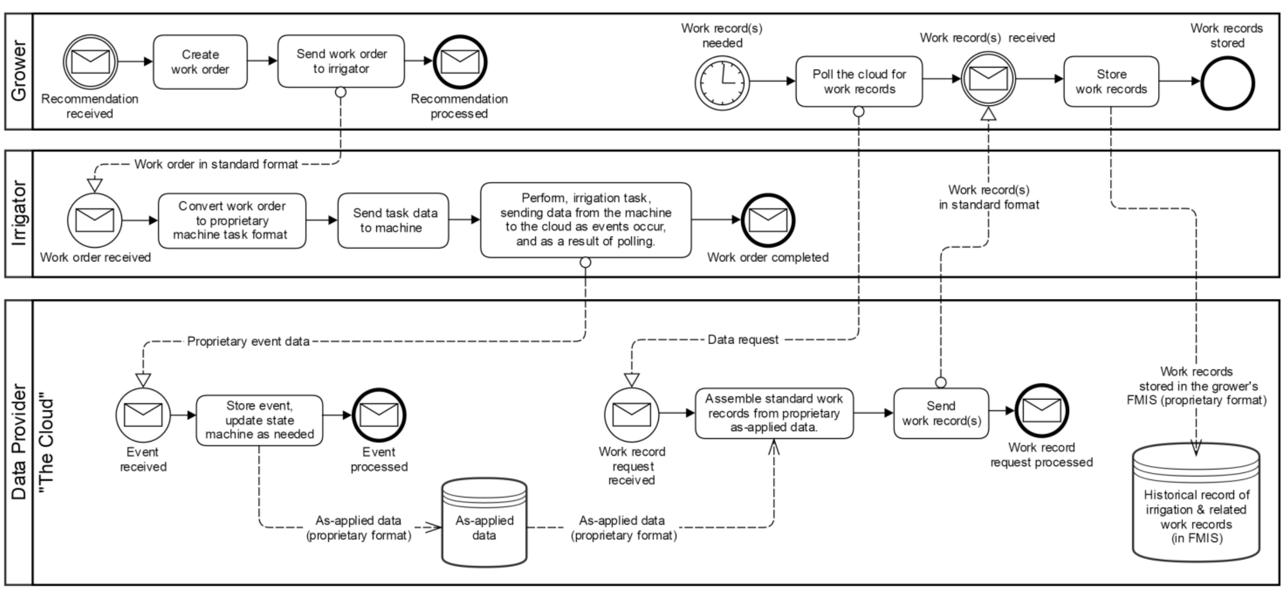

Figure 5: BPMN diagram for Operations.

Figure 6 shows three different processes involved in irrigation observations (in addition to the repeated first process above).

- Grower shares Crop Plan with Consultant, kicking off the Recommendation-creation process.
- Consultant starts season upon receipt of Crop Plan, enters a loop of requesting data from Service Provider(s), using it to create a Recommendation, and sending that to the Grower loop executes until end of season.
- Data Provider honors requests for Observations & Measurements data.

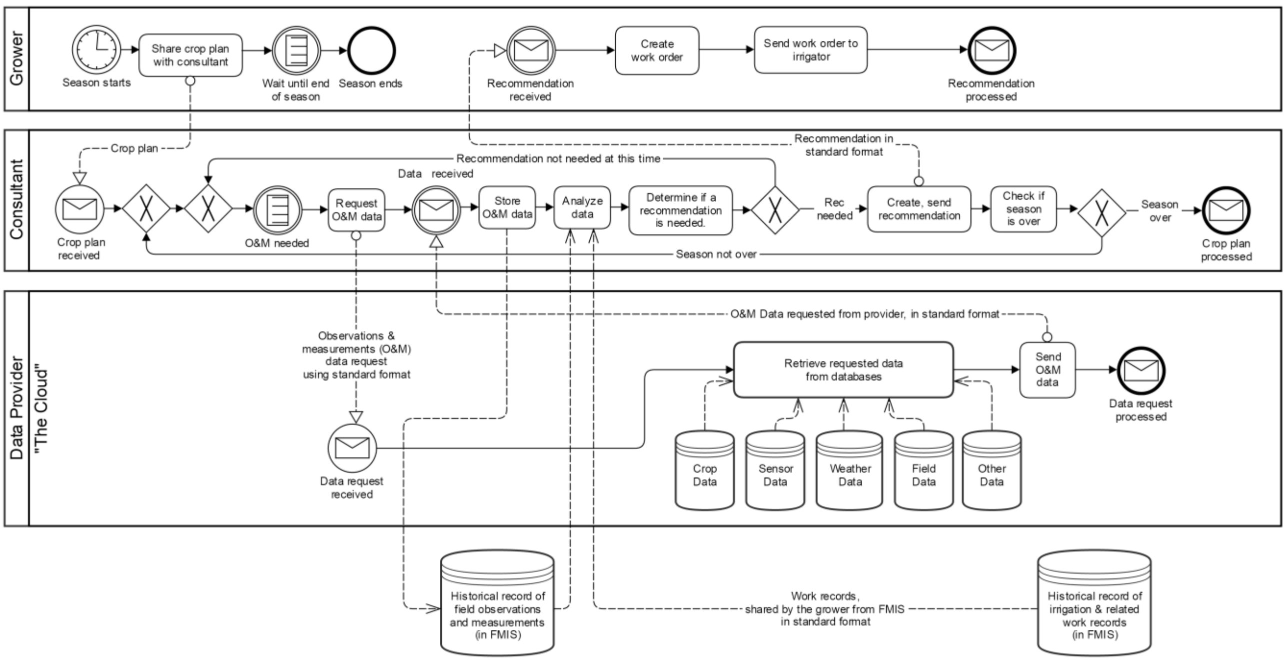

Figure 6: BPMN diagram for Observations.

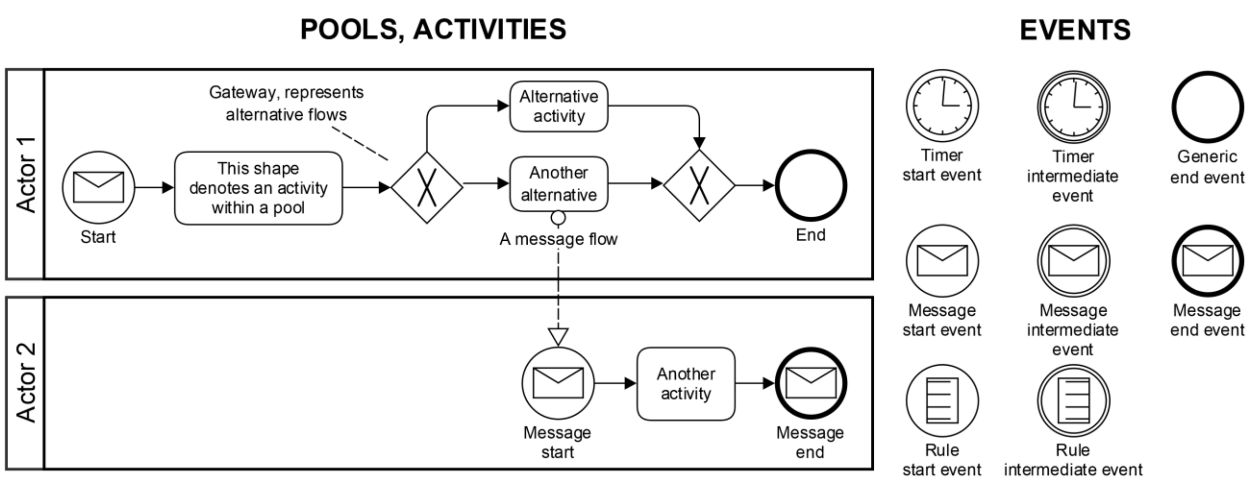

Figure 7: Key to interpret the symbols used in the BPMN diagrams shown in Figures 5 and 6.

PAIL Data: Basic Concepts

Identity

Many objects specified by the proposed PAIL standard are used *by reference* in other objects (for example, a grower, farm and field may be referenced in a work order) and thus need identifiers that can be used by the referencing object. A Unified Modeling Language (UML) class diagram (International Organization for Standardization, 2005) is the mechanism used by PAIL (and other AgGateway precision agriculture-themed standards work) to do this referencing among objects (Figure 8). It centers on an object class called CompoundIdentifier, which provides objects with a simple integer identifier (the ReferenceIdentifier) for use in the local scope of any instance of a data model, and allows associating an arbitrary number of (optional) unique identifiers (the list of UniqueIds) to that ReferenceId.

Each UniqueId, in turn, can be of four different types:

- A Universally Unique Identifier, or UUID (Leach et al., 2005).
- An arbitrary string (to accommodate proprietary alphanumeric identifiers)
- A long integer (to accommodate proprietary integer identifiers)
- A uniform resource identifier, or URI (W3C/IETF, 2001).

Time

Accurately capturing the time at which various events happen is an important part of agricultural record keeping. This is particularly true in irrigation, where water volumes are frequently calculated as a flow rate (e.g., in gallons per minute) multiplied by a duration. The documentation of an event time uses a simplification of the TimeScope used in AgGateway's ADAPT toolkit (AgGateway, 2016). The simplification consists of two timestamps, a required Context attribute that specifies the meaning of the TimeScope through an enumerated vocabulary (not shown), and an optional human-readable Description.

Reference, Setup, and Configuration Data

Reference and Setup Data as providing context to the Core Documents is shown in Figure 2. Their role is explained in greater detail in Figure 8.

Reference data refers to information that a manufacturer makes available for the purchase, setup and/or use of their products, and pertains to *all instances* of a manufacturer's equipment and/or product and product components; i.e., reference data is not grower-specific or specific to an individual sale or single instance of a thing. For example, the product name, EPA number and active ingredients are reference data for a crop protection product, but a lot number is not. In another example, the model and series number are reference data for a center pivot irrigation machine, but the serial number is not.

The intent is to share reference data sets across the whole industry so that different stakeholders can interpret shared documents the same way. This includes names and identifiers of seed varieties, crop protection products, active ingredients, etc. AgGateway has several teams working to create reference data sourcing infrastructure for the industry. (AgGateway, 2015A).

Setup data provides information needed to set up data exchange between the grower and machinery or other actors (e.g., crop advisors.) It refers to two categories of information. Unlike Reference Data, Setup data is grower-specific. The two types of setup data include grower data and configuration data.

Grower Data represents basic information about the grower, farm, fields, and actors. This may include farm names, field boundaries, the specific products the grower has a permit to use, etc.

Configuration Data specifies the state of specific instances of things such as farm equipment and instruments (e.g. soil sensors, irrigation pivots, combines, etc.) This may include their location, what they are connected to, who installed them, etc.

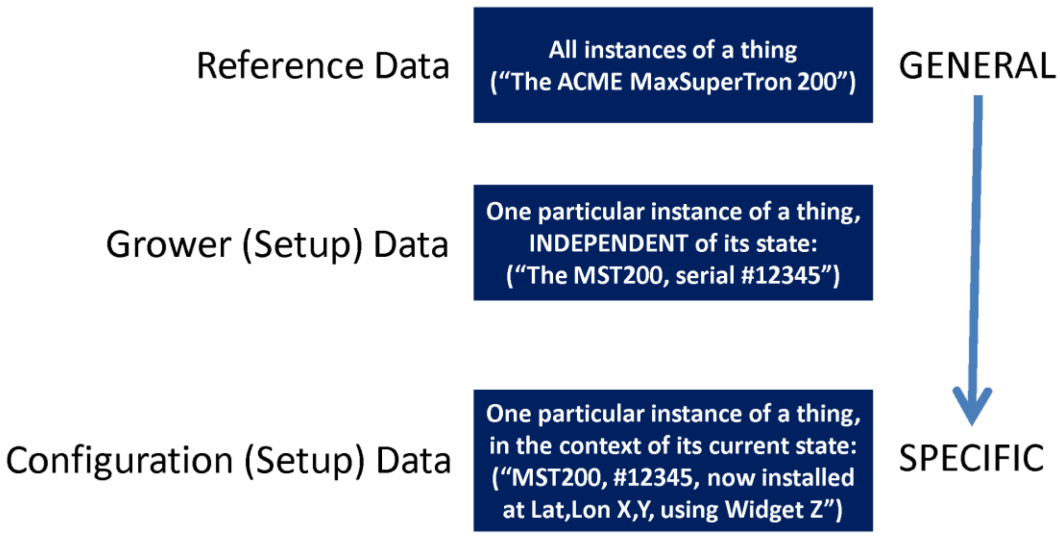

Figure 8: Reference, Setup, and Configuration Data

Data Pedigree

In support of the interpretation of represented data, the PAIL team included functionality for specifying the origin of critical information such as time and location, as well as to specify how the system handles setup data represented in a data file.

- LocationDataSource: Was the location GPS-derived? Was it obtained mechanically (e.g., through an encoder) or estimated? This is important when interpreting data from irrigation equipment such as a center pivot, where the quality assurance procedures to use for different sources of position data might vary (e.g., ensuring accurate GPS-derived positions may require trimming / removing trees that may obscure the sky near the edge of a field, whereas ensuring accurate mechanically-derived positions may require ground-truthing the accuracy of the reported azimuth of a pivot.)
- TimeDataSource: Were the recorded times derived from a GPS? Were they server-mediated when an event was uploaded by the telemetry system? This knowledge is important because the latter option is susceptible to introducing event timing errors under conditions of telemetry system communication errors, whereas the former is not.
- SetupDataPedigree: Is the system keeping track of changes in setup data and reporting the corresponding time series of setup information along with the communicated data, or is it only keeping track of the latest setup? This has important implications for a user: in the latter case, the user would need to access data often to keep accurate track of changes in setup (such as the length of a center pivot) that may affect the meaning of reported data.

The intent of recording this information is not in any way prescriptive; while it is undoubtedly more convenient for a user to have the most accurate and complete options available for these kind of data, there are many legacy systems installed that produce valuable data; the purpose of the pedigree data is to provide the consumer of PAIL data files with valuable information for interpreting exchanged data.

Documents

As architected by AgGateway's SPADE (AgGateway, 2015) and ADAPT (AgGateway, 2016) teams, the five Core Documents mentioned earlier share most of their attributes. Specific details about the different attributes in the Document-derived classes are outside the scope of this document; for the moment, it is enough to note that they answer the following questions:

- **What**: The products or services being applied, or the data being reported.
- **Where**: Grower / Farms / Fields / Cropzones / GPS locations.
- **Who**: People involved and their role: operator, agronomist, trucker, etc.
- **When**: When should / did the operation happen?
- **How**: Product rates, equipment settings, etc.
- **With What**: What equipment is involved?
- **Context items**: A generic system to encode geopolitical-context-dependent information such as (for the US) FSA, EPA, DOT numbers, harvested commodity codes and other geography-specific data that growers must track for insurance and other purposes.

It should be noted that the actual PAIL implementation does not include the abstract Document class. Consultation with developers on the team suggested that implementing the individual child classes separately in the schema (as opposed to extending a Document data type) was in line with the "simple beats clever" approach discussed earlier, and desirable for their production environments.

The Draft Standard and the Schemas

The draft standard (ASAE X632) being proposed by the PAIL team has three parts (a fourth, pertaining to pumps, is in development). Each part includes an annex with a data schema covering the data presented in that part of the standard, as follows:

Part 1: **Common elements** is meant to be used throughout the rest of the standard. They include definitions, business process models, core concepts, product reference data, and setup data.

Part 2: **Operations** include Recommendations, Work orders and Work Records (Plan is out of scope in the first version), and irrigation-equipment-specific, reference data.

Part 3: **Observations** include Observations & Measurements (O&M) and their corresponding Reference (e.g., sensors, loggers, codes for features of interest), and setup data.

Discussion

Development philosophy

The PAIL project has sought to develop a common language that enables integration of multiple, disparate technical tools and sources of water management data. Working with a large variety of tools and data sources requires more expertise than any one discipline or entity can provide; it requires a collaborative approach. In "The Cathedral and the Bazaar," Raymond (2001) describes two philosophies of software development:

- The Cathedral is essentially the traditional academic approach where a group of experts and thinkers apply their substantial knowledge to a problem, test it, and deliver it to the expected consumers via publications, seminars, and classes. This approach has its benefits. The cathedral can produce solutions that are cohesive, clearly scoped, and well-founded in research. The disadvantage is that these solutions do not always accommodate the practical realities of the practitioners. This problem usually emerges from a desire to avoid complexities that would complicate an otherwise simple conceptual framework or when the complexities are caused by issues unrelated to the application domain. Those omissions are often perceived by practitioners as a lack of understanding of real-world conditions and leads to the "Ivory Tower" perception of academic solutions.

- The Bazaar is an open approach where anyone can participate (within bounds of reason). Participants are expected to contribute and the major impacts come from those who do most of the work. The Bazaar approach is messy, slow, and often contentious. However, the Bazaar has a significant advantage. The result is a product the practitioners need. The nature of participatory development means that, by the end of the development cycle, practitioners have already adopted the new system. This contrasts with the Cathedral approach, where motivating adoption is the critical and last step of the development process.

PAIL's development has followed the bazaar model. Any corporation or individual can join AgGateway and participate in the development of a standard. As of this writing, the development process has gone on for nearly three years and by the time the standard is released, several companies will have already adopted an earlier version. Those companies are the same ones that helped develop the standard.

A vehicle for research

PAIL can also provide value to the research community. Many decision-support system (DSS) tools are developed by researchers with the intention of providing growers an easier way to implement robust management practices. These DSS tools incorporate advanced analytical methods and often include field validation that demonstrates their potential for resource conservation, improved efficiency, or greater profitability. A problem is that the tool itself, however, is typically developed by a graduate student whose field of study is not interface design or software engineering, and who does not necessarily use robust industry standard practices for software development. This lack of standard practices in development becomes an obstacle to industry adoption. Additionally, when the student graduates, development stops and does not continue unless the principal investigators can find additional funding. The end result is that the DSS tool will "sit on a shelf collecting dust", be perceived as no longer in active development, and be abandoned by users.

Grant-driven research is not an optimal framework for developing and maintaining applied, production oriented technical tools. These tools require customer support, continual debugging, and a commitment to evolving software for customer's needs. Commercial development is geared towards those needs and software companies are successful because they provide those services effectively.

Standardized interoperability provides a means for researchers to deliver research products, in the form of DSS tools, without the burdens associated with maintenance and customer support. The DSS tools can be written to interact with the interfaces or data formats defined by the PAIL standard, freeing the researchers (and the graduate students) from the need to build, maintain and support a "user friendly" interface. Instead, companies can integrate the DSS tools into their products and focus on providing the user interface and customer support. Thus, the PAIL standard is a means to deliver the benefits of research to growers without the burden of continually requiring funding to support maintenance.

There is another research-oriented aspect that is an indirect consequence of the bazaar model of development. Companies that drive PAIL's development are focused on providing services that are needed now or in the near-future. To be useful, the standard must be relevant to current practices. Research, on the other hand, is focused on developing new tools, which may require data or concepts not yet in use by industry. Because the standard is focused on current practices, it could conceivably not have sufficient constructs to support new tools. Significant effort was made to develop a standard that is generic enough to avoid these conflicts but no standard can account for every eventuality. When a researcher encounters a situation where a new tool cannot be expressed in PAIL, this is an indirect indication of a significant incompatibility with current practices. Such an incompatibility will motivate a researcher to educate the industry, propose a change in a practice, or suggest a modification to the standard itself.

A framework where irrigation is integrated with other field operations

The ISO11783 data format (International Organization for Standardization, 2015) is commonly used to represent planned tasks (i.e. work orders) and actual tasks (i.e. work records) for the field operations of planting, tillage, crop protection, crop nutrition and harvest. It is not commonly used in irrigation for reasons that can be found in the format documentation. For example, ISO11783 cannot easily accommodate the radial geometries inherent in center-pivot systems. Also, the ISO11783 format is complex to understand and pervaded by tradeoffs (such as avoiding the representation of floating-point arithmetic). The ISO11783 format, while appropriate at its time of conception, is not necessarily useful today. The PAIL standard, on the other hand, is highly aligned with the new ADAPT object model (AgGateway 2016) which retains backward compatibility with ISO (for the benefit of the previously-mentioned field operations). It provides a richer, business-process-oriented semantics. The ADAPT design allows irrigation to coexist with the other operations as part of a grower's business process. In the context where growers must comply with complex regulatory requirements as a cost of doing business (e.g. reporting on crop nutrition products applied through irrigation), this alignment with ADAPT is likely to be very advantageous for growers.

Conclusion

The goal of the PAIL project is a data exchange standard that creates a “common language” for irrigation technology. The standard will promote adoption of evidence-based management practices by making technical tools easier to integrate into a farm enterprise.

The PAIL team developed the standard by first creating process models, using Use Cases, User Stories, and BPMN diagrams, to describe irrigation management. The process models were created from a grower’s perspective and represent management practices as they are now rather than an idealized version. Based on these process models, the team designed a robust data model that incorporates all relevant data flows and messages. The data model is rendered as an XML Schema, which will be available publicly with the publication of the standard. Two field trials have been undertaken to validate the efficacy of the standard and to demonstrate its utility in actual irrigation settings. Trial results can contribute to the documentation of the standard and be the basis for training materials.

The PAIL data exchange standard will be submitted to ASABE for balloting in Q3/Q4 of 2016. Once accepted by ASABE, the PAIL standard will also become an ISO standard. Development on the PAIL data exchange standard will continue even after it is recognized by an international standards organization. The PAIL team is currently working on additional sections that cover drip irrigation, pumping systems, and testing. Any person interested in participating on the PAIL team should contact member.services@aggateway.com.

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