

INFRASTRUCTURE INVENTORY AND GIS MAPPING FOR CANAL IRRIGATION DELIVERY SYSTEMS

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ABSTRACT

A comprehensive inventory of canal infrastructure and subsequent mapping is critical to respond to challenges facing irrigation companies and districts. This seems self-evident and obvious, but this information is seldom gathered and maintained because present-day irrigation entities are tasked with operation and maintenance of canal infrastructure that can be over one hundred years old. Typically, there are significant financial constraints and companies operate in a “crisis management” mode, where only the most pressing needs are addressed as they arise.

Modern irrigation in the western United States is facing many new challenges, ranging from water conservation and environmental considerations to urbanization within the system service areas. Additionally, recent drought conditions, the rising costs of labor and fuel, and the reduction in cost of canal technology have prompted many irrigation districts and companies to consider canal modernization. Accurate infrastructure mapping and implementation of geographic information system (GIS) technology is the first step in developing a comprehensive approach to these challenges. Mapping efforts are enhanced through the use of GIS and global positioning system (GPS) technology combined with hand-held computing.

The GIS and infrastructure mapping supports the efforts to address these challenges, through identification of critical structures, priority improvements, and support of desktop analysis, modeling, and planning. The GIS can also be further enhanced through the development of tools to streamline operations and integrate with other systems, such as data management, water ordering and billing, and institutional planning.

INTRODUCTION AND BACKGROUND

Agricultural irrigation in the western United States was characterized by the development of storage reservoirs and canal systems for conveyance and distribution beginning at least 150 years ago. Today irrigation systems in the western United States range from individual irrigators irrigating several hundred acres to the Imperial Irrigation District which serves approximately 450,000 acres in southeastern California.

Today, irrigation companies and districts are faced with a number of challenges driven by both internal and external forces. Irrigation infrastructure in use today is often past its

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useful lifespan, contributing to system-wide inefficiencies in the use of both water and human resources. Irrigation systems have evolved throughout their history to meet the demands of their water users and, often, little effort was made to keep accurate mapping of minor or abandoned structures. Historic irrigation infrastructure is “lost” as a result of lost institutional memory and can exacerbate system inefficiencies through uncontrolled leakage and seepage.

External forces, such as urbanization and increasing pressure to conserve water for environmental, municipal, and industrial uses, further challenge historic irrigation practices and water use by irrigation entities. The West is home to most of the nation’s fastest growing states and cities. Often, people in these communities are new to or detached from an area’s agricultural and irrigation traditions, leading to increased scrutiny of irrigation practices and conflict. Conflicts between agriculture and environmental concerns have led to several well-publicized regional crises. The unique character of irrigation systems throughout the West further complicates these issues. A patchwork of state laws, customs, and historic operations combined with the unique geography and regional agricultural demands has led to the development of irrigation systems in all shapes, sizes, and operational complexity. One size does not fit all!

On top of it all, irrigation entities struggle with the cost of addressing and adapting to these pressures. Agricultural producers are often unable to afford the higher assessments necessary to address the myriad pressures facing their irrigation water provider. Many entities operate in a continual crisis management mode and are only able to respond to their most dire needs, while others continue to make interim improvements to their system, foregoing the high costs of meeting their true rehabilitation needs.

To adequately address these challenges, irrigation entities must have detailed understanding of their irrigation infrastructure, water rights, on-farm irrigation systems, cropping patterns and water use, return flows, land-use plans of the neighboring (and encroaching) urban areas, easements, rights-of-way, construction activities of local government and commercial entities, local environmental issues, stormwater, and liability due to flooding and injury, and myriad other issues. Further staff burdens result from addressing the needs, concerns, and requests for information from irrigators under the system, local governments, environmental groups, homeowners groups, realtors, developers, etc. These issues are much the same as are faced by local utilities, but irrigation entities often have significantly less budget, staff, or in-house expertise in these matters.

These pressures and the availability and decreasing cost of technology have begun to allow irrigation entities to implement much needed improvements which help confront some of these challenges. New lining and piping technologies, structures with gates actuated using supervisory control and data acquisition (SCADA) technology, and the ability to inexpensively and accurately measure flow and alert personnel to alarm conditions have begun to allow irrigation entities to address some of the external pressures that they face. The reduction in cost of personal computers and software has also made it affordable to implement geographic information systems (GIS) for irrigation

entities. GIS, and the associated data-gathering efforts, is the first step to planning a comprehensive response to the issues challenging an irrigation entity.

GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems are a powerful software tool used to store, analyze, manage, and display geographically-referenced data (ESRI, 2009). GIS features a suite of customizable tools and applications which allows users to perform many types of analyses and display the results in a geographic context which is both easy to understand and communicate to others. Most fully-featured GIS software includes powerful programming tools in addition to the mapping and database functionality, which allows the customization of GIS to a huge number of specific applications.

Many irrigation entities do not have sufficient knowledge of their existing operations to begin to address the challenges cited previously. Often, there is not an accurate, up-to-date map of the irrigation system which depicts currently used infrastructure in the context of the service area and surroundings. It is important that an irrigation entity understand basic GIS concepts, existing and potential future challenges to irrigation operations, and have a vision for what the future GIS tools and information may be used for under the system. This understanding will help define the acquisition of data and drive the development of appropriate tools for use in analyzing and accessing the data.

Development of a GIS for an irrigation entity involves several steps (Figure 1):

1. Identification of appropriate GIS and mapping goals.
2. Selection of a suitable software platform.
3. Acquisition of publically-available data and mapping.
4. Collection of relevant data about the system.
5. Development of tools to use or access the data.
6. Regular database maintenance and updates.



Figure 1. Development of GIS for Irrigation Applications

Identification of GIS and Mapping Goals

The most critical step in the development of any GIS or mapping project is to adequately understand the goals that the effort is intended to address. Common goals for the development of a GIS or irrigation system mapping may include:

1. Aid for personnel training and succession planning.
2. Support planning for rehabilitation or modernization efforts.
3. Support system-wide water budget analysis to quantify consumptive use or return flow patterns.
4. Managing urbanization within the system service area.
5. Implementation of an infrastructure management system.
6. Tool to educate irrigators or other members of the community about the irrigation system and its importance in the community.

The goals identified will help to guide the rest of the process, in particular the data collection effort. The data collection effort is the most time-consuming and expensive aspect of GIS implementation. Detailed understanding of the goals and future uses of the GIS will focus on the critical data and ensure that the appropriate data are collected.

Selection of a Suitable Software platform

There are several GIS software packages currently on the market which may be suitable for use by irrigation entities. GIS software is made available through two routes; proprietary software sold through license, or open source (non-commercial) software. Commercial software includes many of the well-known, widely-used GIS packages including ArcMAP and ArcINFO by the ESRI and Map3D by Autodesk. There are a number of other commercial GIS software packages which may be appropriate to irrigation district applications. This software ranges in price and capability, and is typically characterized by the need to purchase and maintain a license, as well as the availability of technical support and training in the use of the software. The examples given in this paper were prepared using the ESRI ArcMAP software. ESRI products are the industry-standard GIS software and are widely used.

Open-source software is non-commercial software that is typically developed and distributed free or for a nominal charge. This software is typically not licensed and can be downloaded from the internet. GRASS, prepared by the U.S. Army Corps of Engineers, is a widely-used, high capability open-source GIS. There are a number of other open-source GIS software packages which may be useful in these applications. This software typically includes a written manual, but typically does not include technical support or training.

Acquisition of Publically-Available Data and Mapping

There are many types of spatial data that may be relevant to the development of a suitable GIS for an irrigation entity. These data may include:

1. USGS quadrangles.

2. Aerial photography covering several years (USGS DOQQ imagery or NAIP imagery are widely available).
3. Satellite Imagery (infrared and other bands may be useful in determining irrigated areas).
4. Soils mapping by the NRCS.
5. USGS Digital Elevation Models (DEM).
6. TIGER (Topologically Integrated Geographic Encoding and Referencing) data collected by the U.S. Census Bureau which include roads, buildings, rivers, lakes, etc.
7. Cropping patterns.
8. Land-use mapping prepared by federal, state, or local agencies.

These data and many others may be available through a variety of sources including federal, state, and local government agencies, GIS clearinghouse websites, and commercial websites. Typically, these data are georeferenced to a known horizontal coordinate system and vertical datum (if applicable), which allows the GIS software to correctly locate the data in space and relative to other data that may have been acquired.

Collection of Relevant Data about the System

Collection of field data is typically the most critical and costly element in the development of a useful GIS for an irrigation entity. As described above, irrigation system mapping, if it exists, may be out-of-date, generally insufficient for needs, and not reflective of current surrounding infrastructure, land uses, or irrigation system infrastructure. Irrigation entities can benefit from a detailed knowledge of infrastructure on their canal systems, ranging from river diversion to farm turnout and including infrastructure (i.e. road crossings) that may be owned by third-parties.

There are a variety of hand-held inventory-grade and survey-grade devices which facilitate these data gathering efforts. Typically, these devices contain integrated global positioning system (GPS) capabilities which allow for the collection of coordinate and elevation data at desired locations. Often, these devices also employ a mobile device-based version of the GIS software (e.g. ArcPAD for ESRI-based systems) which allows for the development of the system GIS in the field. Some software allows for the development of an input form or “questionnaire” which prompts field personnel to gather particular data about structures included in the survey and can include “pull down” menus to increase data collection speed and accuracy. Additionally, inaccurate linework contained on the publically-available base mapping can often be corrected in the field by personnel observing the particular feature, resulting in highly-accurate mapping.

Development of Tools to Use or Access the Data

Once data has been collected and assembled, as described above, the GIS is ready for use (Figure 2). Depending on the GIS goals, the standard query and analysis tools may be sufficient for the user’s needs. These tools are often suitable to specific, Boolean queries (i.e. show me all structures in “poor” condition on the “Smith” lateral). Other, more

sophisticated analyses are also available using tools that may be available as add-on modules (i.e. show me all “turnouts” that are contained in the boundary of the proposed “Smith PUD” development. This analysis would require that fields served by turnouts be identified and intersected with the location of the Smith PUD provided by the local government). These basic analyses and queries may be sufficient to allow the irrigation entity to employ GIS to manage the system and meet many of the goals described above.

There is no limit on the number and types of tools or interfaces that could be developed to interact with the data that is assembled. It is possible to develop linkages between the GIS database and other data management programs which would allow the development of a virtual “file cabinet” for storage and retrieval of data based on geographic location. This would allow all data related to a particular turnout, field, or structure to be available at the click of a button and would save time currently spent searching in physical file cabinets. The amount of information which could be made available in this manner is limited only by the budget (data availability could be phased to meet budget constraints), computer storage space (approximately \$100 per terabyte currently), and the imagination or needs of the end user.

These tools could also include productivity enhancements for irrigation system personnel, such as mailing list generators (i.e. identify an upstream structure and generate a list of downstream users to notify about planned maintenance) or an email tool which packs user selected data to respond to outside requests for information (i.e. a developer would like mapping of irrigation system easements and infrastructure on a parcel).

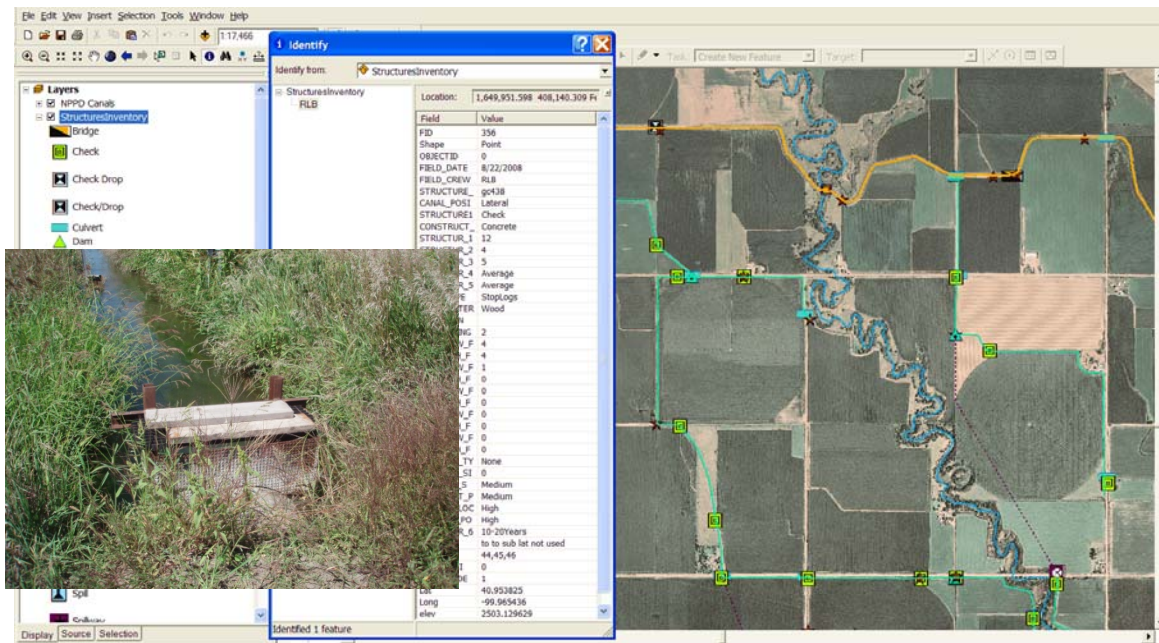


Figure 2. GIS screen capture showing canal inventory and structure database query.

Regular Database Maintenance and Updates

Depending on the GIS goals and the size of the irrigation entity, development of a GIS can be a significant investment of time and money. This investment is protected and extended through regular updates and maintenance of the database. Often, third-party data is updated annually and the data is available on an ongoing basis via subscription. Irrigation system data should be updated as-needed, depending on the implementation of infrastructure improvements or other relevant changes to the system. The ultimate utility of this tool, as with other types of tools, depends on the accuracy and the timeliness of the data contained within.

NEXT STEPS

The GIS is a tool that can be used to assist with the management of numerous issues under a typical irrigation system. The specific applications depend on the system goals, data availability, sophistication of the operator and tools, irrigation system size and complexity, and the types of challenges facing the entity. As described previously, one size does not fit all, so a series of potential applications will be illustrated.

Planning for Canal Modernization

Canal modernization is a generic term for the variety of infrastructure and automation improvements that often result in canal operations which conserve water and human resources. Often these studies are completed by consultants who do not have detailed, operational knowledge of the canal system at the time that the study begins. Effective canal modernization planning requires detailed understanding of canal operations and the external challenges that may be confronting the irrigation entity (Figure 3). Detailed mapping and infrastructure data is critical to the development of adequate canal modernization planning. The following basic data are useful in these support tools:

1. Aerial photography. Aerial photography conveys significant information about the nature of a canal and its surroundings.
2. USGS quadrangle or other topographic data. Topography is a critical consideration in the planning for communication systems which often accompany SCADA systems.
3. Basic irrigation system data. Information regarding service area, canal alignment, check and turnout location, canal spills and returns, flow measurement, etc. is critical to understanding the basic canal system operations.
4. Detailed irrigation infrastructure data. Detailed structural information (i.e. structure type, structure condition, gate type, structure importance) is critical to development of improvement priorities, identification of the appropriateness of retrofit versus replacement, etc.

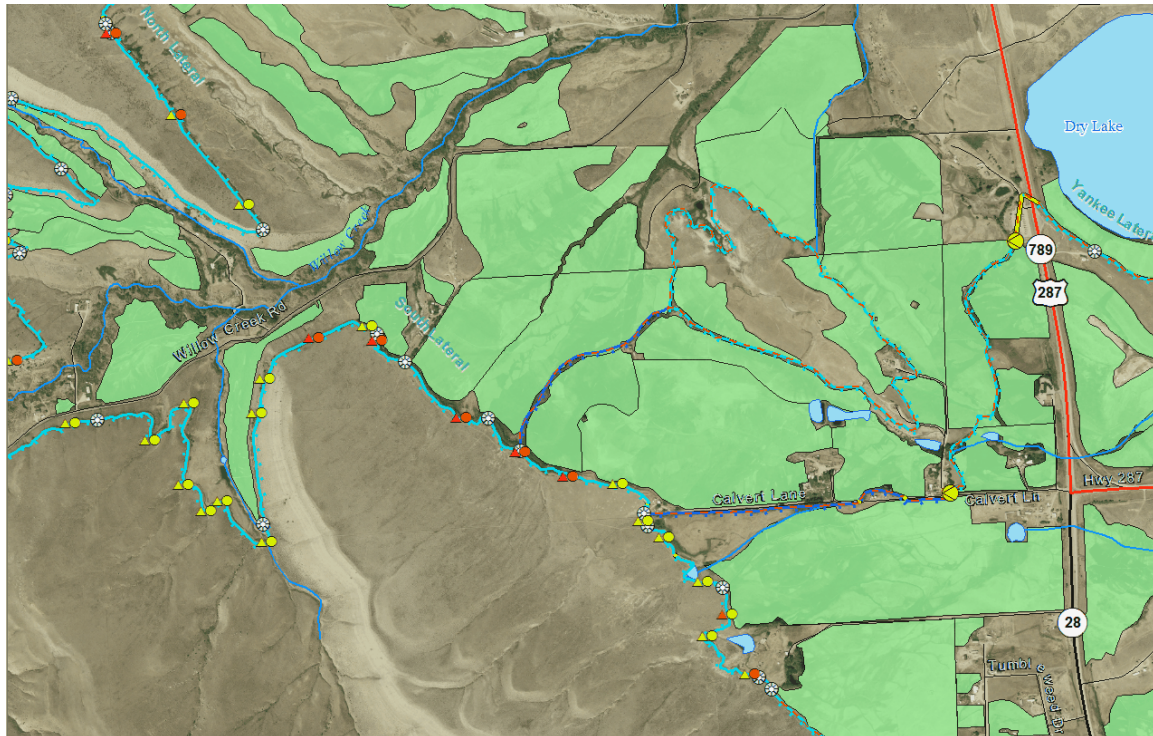


Figure 3: GIS created map showing canal and bank condition, irrigated lands, and structures.

Responding to Urbanization

Responding to urbanization pressures is a common external challenge facing many irrigation entities in the western U.S. The specific nature of this challenge varies by region or system, but the challenge has many common features. It is common for irrigation entities to have no idea about the planning activities and regulations of local governments, and for local governments and developers to have a limited understanding of irrigation operations, infrastructure, and needs. Often this lack of information is manifested as a conflict between these interests over development of a parcel located within the irrigation service area or adjoining part of the irrigation distribution system. Inevitably, this conflict occurs well into the development process, potentially resulting in costly redesign or even legal actions. It is essential that irrigation entities approach local government, or vice versa, with needs and concerns related to urbanization in the vicinity of irrigated ground or infrastructure. Ideally, the irrigation entity and local government can work together to ensure that all proposed development meets the needs and requirements of both entities during the planning process.

Local government entities are often unaware of the extent of irrigation infrastructure and service area. Providing local government entities with the following information may assist them in providing adequate information to prospective developers to minimize the potential for future conflict:

1. Basic irrigation system data. Information regarding service area, canal and lateral alignment, check and turnout location, canal spills and returns, flow measurement, etc. is critical to understanding the basic canal system operations.
2. Irrigation system property data. Recorded or prescriptive easements for canal conveyances, access and maintenance easements, and other property matters are essential. Some easements may not be recorded so this information is invaluable in preventing future conflicts.
3. Irrigation hazards mapping. Canal leakage or overtopping due to unusual or unforeseen circumstances has been a known hazard since the development of irrigation canals. Often these hazards have been manageable and have not caused significant damage in a historically agricultural area. It may be useful to provide information about known areas of concern to project developers to protect the irrigation entity against increasing risk of significant damage following urbanization.

GIS data will often be desired by government entities to complement their own data. In this situation, long term reciprocal sharing of data can become a routine and desired outcome.

Documentation of Beneficial Use

Many Western states allow water rights to be changed to other locations or uses, or may require that beneficial use be documented. Development and maintenance of a GIS is an excellent vehicle for gathering, storing, and managing data which are important to these efforts (Figure 4). Once gathered, these data can be used to show irrigation, to support water budget analyses, etc. There are several basic pieces of information which are critical to these efforts:

1. Aerial photography. Aerial photography over many years provides simple evidence of irrigation that is essential to many water rights proceedings. It is also very useful in documenting land use changes, a “timeline” of urbanization, and other information. A picture is worth a thousand words, as they say.
2. Soil mapping. NRCS soil mapping is typically a GIS-ready product that can be acquired free of charge. This product provides valuable information about the soil reservoir and productivity that is useful for a wide variety of applications.
3. Cropping patterns and irrigation methodology. This information can be reported by irrigators or obtained from the Farm Service Agency. This basic data is critical to determining the consumptive use of water under the system, which is often a component of most water rights proceedings.

4. Basic irrigation system data. Information regarding service area, canal alignment, turnout location, canal spills and returns, other area water rights, etc. is often critical in these types of proceedings.

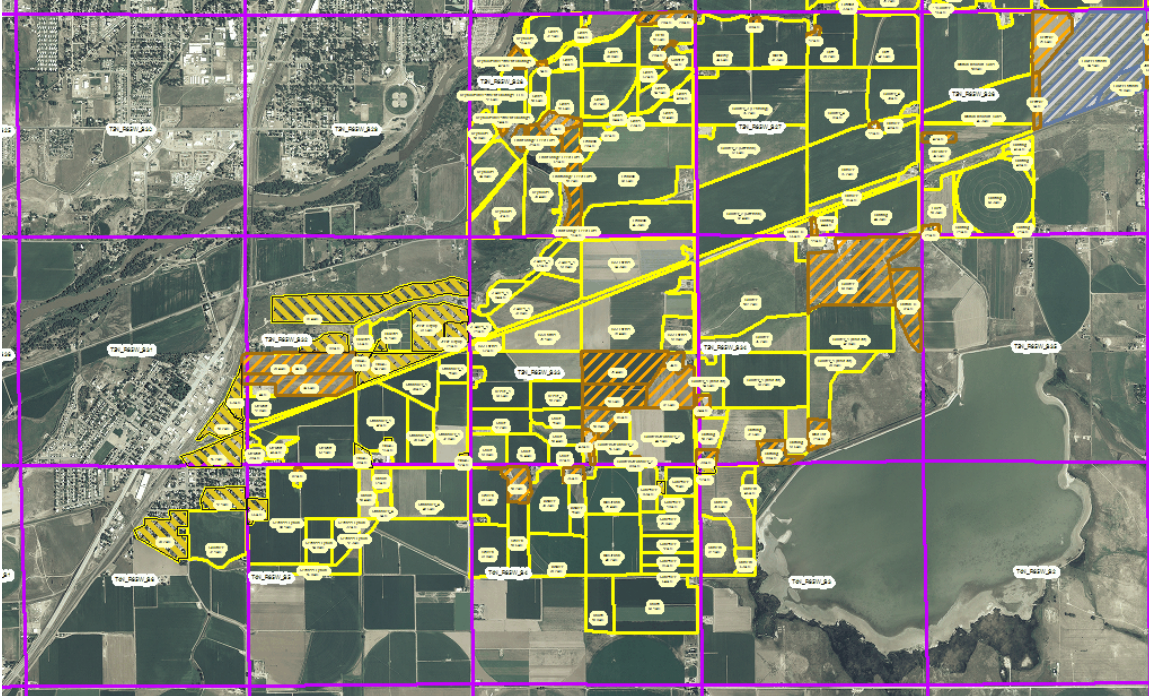


Figure 4: GIS-based analysis in support of historic consumptive use determination.

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