RECLAMATION

Managing Water in the West

Canal Inspection Methods Literature Review

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Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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14. ABSTRACT *(Maximum 200 words)* This literature search summarizes existing knowledge about void and seepage detection methods applied to canal channels. It compiles available field investigation methods that are useful for canal seepage and void detection and evaluation, including visual methods, geophysical survey techniques, and nondestructive inspection methods. The varied techniques identified through the literature search have been evaluated for cost effectiveness, accuracy, practicality for large scale use, and other factors. The ultimate objective of this research is to develop a practical and cost effective single method or suite of methods to better detect and evaluate canal seepage sources and paths. Any method that is identified should be able to be implemented by Regional, Area, and Field Office staff or their respective contractors.			
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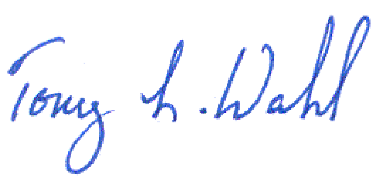

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Executive Summary

Canal inspection is a significant part of the Bureau of Reclamation's Operations and Maintenance program, and regular inspection is required as a part of Reclamation Directive and Standard FAC 01-04. Reclamation is particularly concerned with identifying canals which have potential voids or active seepage that can potentially pose risks to urbanized areas. Some voids and seepage from canals can be detected by regular visual inspections, but methodologies are being researched that allow for identification and inspection of voids and seepage that cannot be detected by visual means alone.

Some traditional methods such as inflow-outflow tests, ponding tests, point measurement, and geologic and hydrogeologic characterization are well understood and are routinely used by Reclamation and other water managers. Therefore, these methods were not further investigated in this study; however, a summary of these methods is included for completeness.

Development of new technologies, methods and practices for subsequent incorporation into Reclamation inspection programs is of particular interest to the Lower Colorado and Pacific Northwest Regions due to recent incidents involving the Central Arizona Project aqueduct and the New York Canal. Determining the best methods to find and quantify the extent of seepage to ensure a breach does not occur on these and other canals is a significant priority for these Regions, with broader potential applicability to all canals.

This literature search is one step being taken to assemble and assess existing knowledge about void and seepage detection methods applied to canal channels. This activity compiles available field investigation methods that are useful for canal seepage and void detection and evaluation. This includes various geophysical survey techniques, and visual and other nondestructive inspection techniques. The techniques identified through the literature search have been evaluated for cost effectiveness, accuracy, practicality for large scale use, and other factors.

The ultimate objective of this research is to develop a practical and cost effective single method or suite of methods to improve detection and evaluation of canal seepage sources and paths. Any method that is identified should be practicable for implementation by Regional, Area, and Field Office staff or their respective contractors. This scoping report is the first step in identifying existing methods. Future work may include rating the existing methods based on a set of criteria to identify the best approach for given conditions. Another future step may include identifying gaps in current knowledge and technology that can benefit from researching new tools or methodologies.

Inspection and Detection Methods

Traditional field seepage tests

The field seepage rates of soils can be measured using traditional methods such as ponding tests, dye tracer tests, and inflow-outflow tests.

Ponding and Dye Tracer Tests

Ponding tests are widely considered the most accurate means of measuring channel seepage and are generally regarded as the best technique against which other methods can be assessed. Ponding tests and dye tracer tests are conducted when the canals are not in use and empty. Traditionally, they are conducted by first sectioning off a portion of a canal, either by creating a temporary impoundment structure or by using a field tool such as a ring infiltrometer. The impoundment structure or field tool is filled with a volume of water and the rate that the water infiltrates into the ground is observed. If a dye tracer is used, it would be added to the infiltrating water and observed in wells or drainage features down gradient. Since it is necessary to carefully control the volume of water that is infiltrating, these tests are often limited to small, discrete sections of canals. Because non-flow conditions can introduce some inaccuracies, these tests are best suited for situations when possible seepage locations have been identified and need to be further evaluated.

Inflow-Outflow Tests

Inflow-outflow tests are another traditional method for identifying seepage rates of soils. They consist of measuring the flows passing upstream and downstream points and then calculating the difference between the flow values. A negative value indicates that the reach is losing water (i.e. water is infiltrating) and a positive value indicates that the reach is gaining water. This method is best suited to long sections of channel that contain apparent seepage, from which there are no diversions, and which contain suitable structures in which to incorporate measuring devices. It is important to also account for other sources of inflow or water loss, such as evaporation or drainage inflows to the canal.

Geologic and Hydrogeologic Characterization

Evaluation of Existing Data

To prioritize the use of expensive methods for studying subsurface conditions, existing information should be reviewed to provide a preliminary understanding of the conditions and to identify locations where new data should be collected.

Existing data may include:

- ***Maps of surface features, including elevations*** – The spatial location and elevation of surface features is very important when trying to characterize the subsurface. Relevant features include canals, wells (both operating and observation), rivers, and land use. The relative location and elevation of these features in combination with other subsurface information (such as well logs) can provide a conceptual understanding of the subsurface.

- ***Well logs*** – A well log is an accounting of differing soils and geologic material by depth that is recorded when a well is drilled. Most states require that a well log be submitted when a well is drilled and many have public databases to access such logs. The logs can be developed by drillers or geologists and the quality of the log may depend on the knowledge and experience of the person recording the log.

- ***Geologic maps*** – Geologic maps are available at a variety of scales and provide a general idea of the geologic conditions in a geographic area. They often include both material classification and structural information (location of faults, etc.).

- ***Construction reports or drawings*** – Depending on the age of the canal, construction reports may be available and may include information about the geologic material near the canal.

- ***Water level data*** – If wells exist near the location in question, there may be water level data that has been collected over time. This water level data can be used to determine the impact of the canal operation on groundwater conditions.

Drilling

When information is not available in a particular location, new wells can be informative. Samples of subsurface material can be collected while the well is being drilled and can be used to determine the stratigraphy of the subsurface. Drilling wells is invasive and expensive; however, the information gained from drilling can often be the best indicator of subsurface conditions in a particular location. In addition, wells can be used to conduct permeability tests and be fitted with instrumentation to continuously monitor groundwater elevations.

Hydrogeologic Characterization

Compiling geologic characterization data and collected water level information can provide an understanding of the groundwater conditions near a canal. Groundwater conditions are often permanently altered when canals are constructed because the seepage from the canal becomes a new source of recharge to the aquifer. In some cases, this has the positive impact of increasing groundwater supplies, and in other cases, it raises the water table to a level that inundates lands.

Water level data from nearby wells can be used to evaluate the impact of the canal on the aquifer. If data is continuously collected and evaluated, anomalies that may indicate additional seepage from the canal can be identified. In addition, data that has been collected over time can be used to determine if elevated groundwater conditions are a result of canal seepage or other recharge sources.

Remote Sensing

Thermal Imaging (Infrared)

One method of detecting or determining seepage is to use thermal imaging, like infrared spectral imaging (Perotti, 2013). This method does not directly measure the flow of water, but rather measures infrared radiation or heat to discover areas of vegetation and/or cooler temperatures that could be caused by seepage from the canal.

Thermal imaging is typically accomplished with the use of aircraft so large areas can be covered in one data-gathering period and then analyzed in the office. It also can be performed with no destructive or operational impacts to the canal.

However, the limitation of this method is that it only indicates areas of possible concern. The cooler temperatures or vegetation growth could be caused by other factors such as a local spring or naturally occurring high groundwater, or even local irrigation in a more urbanized area. Also, this only indicates aspects that would likely be noted in a visual inspection. Therefore, this method is most often employed in large canal systems where visual inspection either has not taken place or is not practical at a desired level of detail (Shutko, 2005).

This method could be useful as a preliminary investigation tool for determining possible focus areas for subsequent visual inspection but there may be limited added value for Bureau of Reclamation canals that routinely undergo full visual inspections.

Self-Potential Method

The self-potential method is based on the measurement of areal variations in electrical potential in a soil mass. There are several possible sources that generate variations of electrical potential, and the source of interest for seepage detection is the electrokinetic, or streaming, potential caused by the flow of an electrolyte (water) over or through a naturally charged solid (soil mass). The method requires the placement of stationary electrodes but can also be used in conjunction with roving electrodes. Because the effect is measured between electrodes, it can only cover areas where electrodes are installed.

Unlike methods that detect just the presence of water, the self-potential method directly measures flow and seepage, resulting in a significant reduction of what could be false positives in areas of saturated soil with no seepage.

The limitation of this method is that the changes in the electric field caused by flow are very small and can be difficult to distinguish from other self-potential sources such as metal in a dam or canal or powerlines in the area (Boleve, 2013).

In fact any buried metal object can cause a self-potential to occur. This can be a significant drawback as canals are often used as utility corridors and therefore have powerlines or pipelines adjacent to the channels.

Ground-Penetrating Radar

Ground-Penetrating Radar (GPR) is a method for measuring soil water content, but does not measure the actual flow of water. It is generally applicable only in investigations of very shallow depths less than six feet (Wadhwa, 2008). GPR has been used for many years and therefore is a well-tested technology, but the method's limitations are also well documented. The presence of large percentages of clay or high water content can often defeat GPR (Wadhwa, 2008). This makes testing from the water side of the canal ineffective, and voids or seeps on the dry side or toe of the canal are often too deep for GPR to be effective. GPR also has limited areal coverage compared to aircraft-deployed thermal imaging. GPR can be towed by vehicle or boat to cover a greater area, but this still leaves limitations of depth.

Due to these limitations, GPR has rarely been used in canal testing. This literature review found only a single application (Wadhwa, 2008); thus, this would likely have limited application in Reclamation canals. It has been used to successfully find voids in other structures such as spillways and outlet tunnels, but to accomplish similar work on concrete-lined canals, the canals would have to be drained which presents a significant limitation.

Electrical Resistivity

Like any electrical conductor, soil possesses an electrical resistance that can be measured and is affected by the properties of the soil and the presence of water. Electrical resistivity measurements in both canal embankments and embankment dams have been used to determine location of voids, and to find moist areas that might be indicative of seepage. There are several methods to determine electrical resistivity. Most methods involve electrodes that send out an electrical signal and a separate set of electrodes to read the signal and determine resistivity.

If the area of concern is specifically known, electrodes can be permanently installed within that area (Pognant, 2013). Then the electrodes can be set to send out a pulse at given intervals with the readings automatically recorded. Therefore, this method can give continuous readings on the resistivity of the embankment material; however, this is limited to the area of permanently installed electrodes.

Another more common deployment method is to set an electrode temporarily in a fixed location while another electrode or set of electrodes is moved by boat, car or other means along the canal embankment to obtain a resistivity profile (Cassel, 2003). With this method large areas along a canal can be covered in a single inspection. However, since the electrodes are not permanently installed, this is a one-time inspection and cannot be used for continuous monitoring.

Reclamation has conducted some work with roving resistivity surveys in the past. In 2009 a survey for canal seepage in the Yuma, AZ area was done as a demonstration project (Kaufmann, 2009). The geophysical survey measured resistivity in the All-American Canal with two methods for moving the roving electrodes:

- a boat towing a line of electrodes through the channel, and
- a person pulling the electrodes while walking along the canal embankment.

Some researchers have seen sudden jumps in resistivity that pinpoint specific sites of potential seepage using this method (Pognant, 2013). Wadhwa (2008) was able to locate potential seepage areas and both water- and air-filled voids beneath a canal. This ability to combine void detection and potential seepage detection in a single method could be a great benefit to Reclamation.

During the Yuma field demonstration (Kaufmann, 2009) researchers were only able to determine the soil types in an area. This indicated some embankments made of materials that had high potential for seepage, but no specific points of seepage were found. Further investigation has shown that the area of inspection did indeed have seepage occurring that the method did not detect.

The primary limitation of resistivity methods is that they only note the presence of water in the soil and do not determine flow. Therefore active seepage and saturated soil would appear to be similar with the use of this method.

Microwave Radiometry

Microwave Radiometry has been used for remote sensing of moist soil areas associated with levees and zones of high groundwater level (Shutko, 2005). This, like thermal imagery, is acquired by equipment attached to aircraft, so this method can cover large portions of a canal or land area. The advantage microwave radiometry has over thermal or infrared imagery is that the microwave energy has some ability to penetrate the ground and indicate conditions under the earth's surface.

This can give some information regarding water content in soil; however, like many of the other remote sensing methods, it only gives soil water content and therefore does not distinguish saturated soil from that which has active water flow. This method would also be unable to distinguish seepage flow from flow from lateral canals or other irrigation systems. Also, it is unclear from the limited research available on the method as to how deep into the soil the microwaves can penetrate and give reliable data. No data below 6 feet was presented in the reviewed papers.

Other Methods

Hydrochemical Tracers

Isotope and tracer investigations can be used in detailed studies to assess channel seepage. Types of tracers used include conservative (non-reactive) chemical tracers such as chloride, and isotopic tracers such as the stable isotopes of hydrogen (deuterium) and oxygen (oxygen-18).

Outputs from these types of studies, combined with water balance estimates, can be used to produce estimates of seepage rates in two ways:

- In a **Mass Balance** approach, the concentration of a tracer in channel water is measured along with other inflow and outflow components. The method combines the use of a water balance and a chemical/isotopic mass balance to estimate two unknown components (seepage, and inflows [precipitation] or outflows [evaporation]).

- **Tracing the Seepage Plume** method uses the hydrochemical/isotopic concentration of seepage water to define the volume of water that has leaked from a channel over a specific period of time.

Hydrochemistry can be used to either estimate the rate of seepage from a water body or to indicate where seepage may be higher compared to other parts of the water body. It is not considered to be applicable for routine channel seepage assessment, but is useful for tracing a plume seeping from a channel into the surrounding groundwater system. This is dependent upon the concentration of the tracer in the water leaking from the channel being different from the tracer concentrations in the surrounding soil and groundwater, as indicated by analyses of selected tracers from a series of monitoring wells.

Use of naturally occurring or artificially enhanced tracers may be valuable if information is obtained on a potential seepage plume over a long time period, and in an area large enough to account for spatial and temporal changes in seepage (Wimmera Mallee Water, 2003). The difficulty with this method is that canal flows limit the time available for sufficient volumes of dosed water to seep into the aquifer and be detected. Another major disadvantage of this method can be the high cost of artificial isotopes and specialized expertise needed for application and evaluation, so this is generally not a practical solution for seepage location identification.

Fiber Optic Sensors

Fiber optics has been widely used in civil engineering applications and for monitoring hydraulic structures such as concrete and earth dams, levees and dikes. The monitoring system is based on a combination of fiber optic sensors and related instrumentation to detect the first steps of internal erosion processes and structural instability. The detection of leaks, an early stage of the internal erosion process, is assessed through temperature changes.

For decades, temperature measurements have been typically recognized as one of the most relevant physical parameters for detecting leaks through embankments (Beck et. al, 2012). Capabilities to measure temperature significantly increased when fiber optic technology allowed distributed temperature measurements that could be used for both long-term leak monitoring and internal erosion early warning systems. The fiber optic Distributed Temperature Sensing (DTS) method was developed at the beginning of the 1980s at Southampton University in England.

A distributed sensor network supported by fiber optics is useful in harsh environments or along structures that span long distances. A large number of sensors can be supported in a single optical fiber line due to the tremendous optical bandwidth and low power loss of the technology. Additionally, such a network has the capability of evaluating several engineering parameters (i.e., strain and temperature) over several miles in various types of large-scale structures. It is a powerful diagnostic instrument for the identification and localization of potential problems. With the widespread use of modern communications technologies, the fiber optic measurements can also be collected and structures can be monitored from a central station several miles away from the site. This remote capability allows immediate detection, so necessary actions can be taken to reduce risk.

However, given the high costs of installation and assembly of a fiber optic thermal monitoring system, the placement of this technology on existing canals is likely to be limited to those reaches that may present potential flood hazards if breached. But this method may be appropriate for integration into new construction where it can be incorporated into a canal or embankment design.

One product (TenCate GeoDetect®) detects both internal erosion and instability through the use of a geotextile with interwoven fiber optic cables that are connected to instrumentation. The system includes both the hardware (geotextile fabric, sensors, instrumentation) and the related software to analyze the data produced from the sensors. The detection of leaks at the early stage of the internal erosion process is assessed through temperature change measurements, while the first stages of embankment settlement or sliding are detected by strain measurement. The interpretation of the raw thermal and strain data combined with signal processing methods would allow the system to send "early warnings" and to be compatible with long-term monitoring. Additionally, the filtration properties of the geotextile increase the stability of the soil, helping prevent the internal erosion process.

For existing structures, the temporary installation of fiber optic technology in specific canal sections or reaches may be effective for assessing potential seepage locations. For example, in research conducted in the Netherlands in 2007, one-mile sections of fiber optic cable were placed at the bottom of canals and connected to DTS equipment (Sensornet Sentinel DTS-LR). This study proved that DTS is effective in identifying seepage in ditches and canals at places that were not known before, and suspected sites of seepage could be confirmed and assessed to determine their exact location and extent. The research also showed that the fiber optic cables could be reused without damaging the fragile glass fiber inside. Bending and stress on the cable during the installation and removal in the canals had no negative impact on the fibers (Hoes et al., 2009).

However, this technology is still relatively new and much research is required before large-scale field deployment is possible: (1) extensive work is required to understand and process the raw measurements into useful engineering quantities; (2) sensor development is still very much in its infancy; and (3) the long term durability of the sensing system in the real world needs to be established (Rajeev, et. al., 2013). The data acquired can also be influenced by several factors, including existing structures (drains, tunnels, etc.), heat transfer from the soil, seasonal temperature variations, precipitation, etc.

Thus, fiber optic monitoring is not yet envisioned as a replacement for the traditional methods of seepage investigations, i.e., local inspections, and geophysical and geotechnical methods. All these methods should be considered to be a set of tools which can be selectively applied on a case-by-case basis for individual canal sections that are being considered for study.

Next Steps

This scoping report is a summary of available literature describing available field investigation methods that can be used to detect canal seepage or voids beneath canals. The methods include various geophysical survey techniques along with visual and other nondestructive inspection techniques. The ultimate objective of this research is to develop a practical and cost effective single method or suite of methods to improve detection and evaluation of canal seepage sources and paths. This scoping report is the first step in identifying existing methods. Future work may include rating the existing methods based on a set of criteria to identify the best approach for given conditions. This work may also include identifying gaps in current knowledge and technologies that may benefit from researching new tools or methodologies.

Appendix

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