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Knowledge Stream

Research and Development Office

Canal Health

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Message from R&D

Welcome to this issue of the *Knowledge Stream* magazine! R&D is excited to share research progress on canal health. This issue highlights better ways to identify and quantify canal seepage to prioritize canal improvements, enhance sustainability, and support water delivery reliability.

Canal sustainability is a priority issue for Reclamation and the western U.S. water management community. Reclamation and partners have constructed over 8,000 miles of canal to service water deliveries. As canals age, water managers seek efficient and affordable ways to inspect frequently, identify seepage areas, and analyze areas of interest to inform response.

In this issue, R&D discusses engagement with Reclamation's infrastructure community to identify priority science and technology needs, all to inform a responsive research strategy. In addition, several promising developments are covered, including:

- A canal seepage assessment framework that can help our infrastructure managers more cost-effectively detect, quantify and analyze water seepage situations.
- Leveraging satellite remote sensing to permit rapid and frequent reconnaissance.
- Using ground surface heat as a tracer to quantify water loss from concentrated seepage.

As always, please enjoy this issue of the *Knowledge Stream* and offer any feedback for continual improvement of dissemination strategies for transferring solutions to users.

Levi Brekke
Program Manager

About the *Knowledge Stream*

The *Knowledge Stream*, published by the Bureau of Reclamation's Research and Development Office, is a quarterly magazine bringing mission-critical news about the agency's innovations in the following:

- Science and Technology Program
- Desalination and Water Research Purification Program
- Prize Competitions
- Technology Transfer
- Open Water Data...and more.

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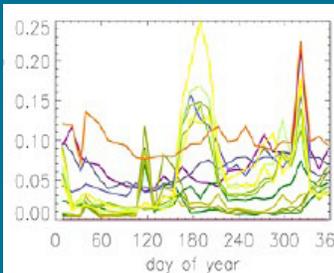
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Covers: FRONT: The Truckee River System, managed by Reclamation's California-Great Basin Region, originates at Lake Tahoe, where inflows provide the initial water supply for the system. When water levels at Lake Tahoe are above the natural rim (6,223 feet above sea level), outlet gates in Tahoe City, California regulate outflows to the Truckee River. BACK: Grand Canal in Maricopa County, Arizona is part of the Salt River Project in the Lower Colorado Basin Region. It includes a service area of about 240,000 acres spanning portions of Maricopa, Gila, and Pinal Counties in central Arizona. The land within the project is furnished a full irrigation water supply from the Salt and Verde Rivers and from 250 groundwater wells. About 26,500 acres are furnished supplemental irrigation water.

Community Needs

Canal Infrastructure Reliability and Sustainability

Reclamation has been delivering water for over 100 years and has constructed approximately 8,000 miles of canal, with 25,000 miles of distribution laterals in the Western United States. The agency's water irrigates 10 million acres of farmland, serves one in five western farmers, and 31 million people use 10 trillion gallons of Reclamation water for municipal, residential, and industrial uses. Most Reclamation canals were built in remote, rural areas. Over the years, increasing populations and expanding communities near these canals have resulted in approximately 1,000 miles of Reclamation canals in urbanized areas.

Achieving safe and reliable water delivery requires collaboration across federal, state, and local governments, as well as private operators and the public. Many of Reclamation's conveyance features are operated and maintained in partnership with irrigation and water districts. Reclamation's [Water Conveyance Program](#) conducts Reclamation-wide asset management activities. This includes maintaining a comprehensive asset inventory, providing policy guidance, planning activities, and ongoing condition assessments to provide effective and transparent solutions and keep water flowing.

Addressing the needs of aging infrastructure is critical to system reliability. Research roadmapping enables Reclamation to determine where future research efforts should be focused in order to provide the greatest benefit. The agency's Research and Development Office enacted several research roadmapping endeavors in order to strategically identify the organization's evolving scientific and engineering research needs. For example, [Short-Term Water Management Decisions: User Needs for](#)

[Improved Climate, Weather, and Hydrologic Information](#) highlighted interagency impacts related to characterizing water availability from hours to seasons. In addition, [Research Priorities for Mechanical Components of Hydropower Units](#) identified opportunities for the enhancing hydropower generation infrastructure. Ecohydraulics mapping is ongoing.

Central to Reclamation's mission in canal water infrastructure are these three research questions:

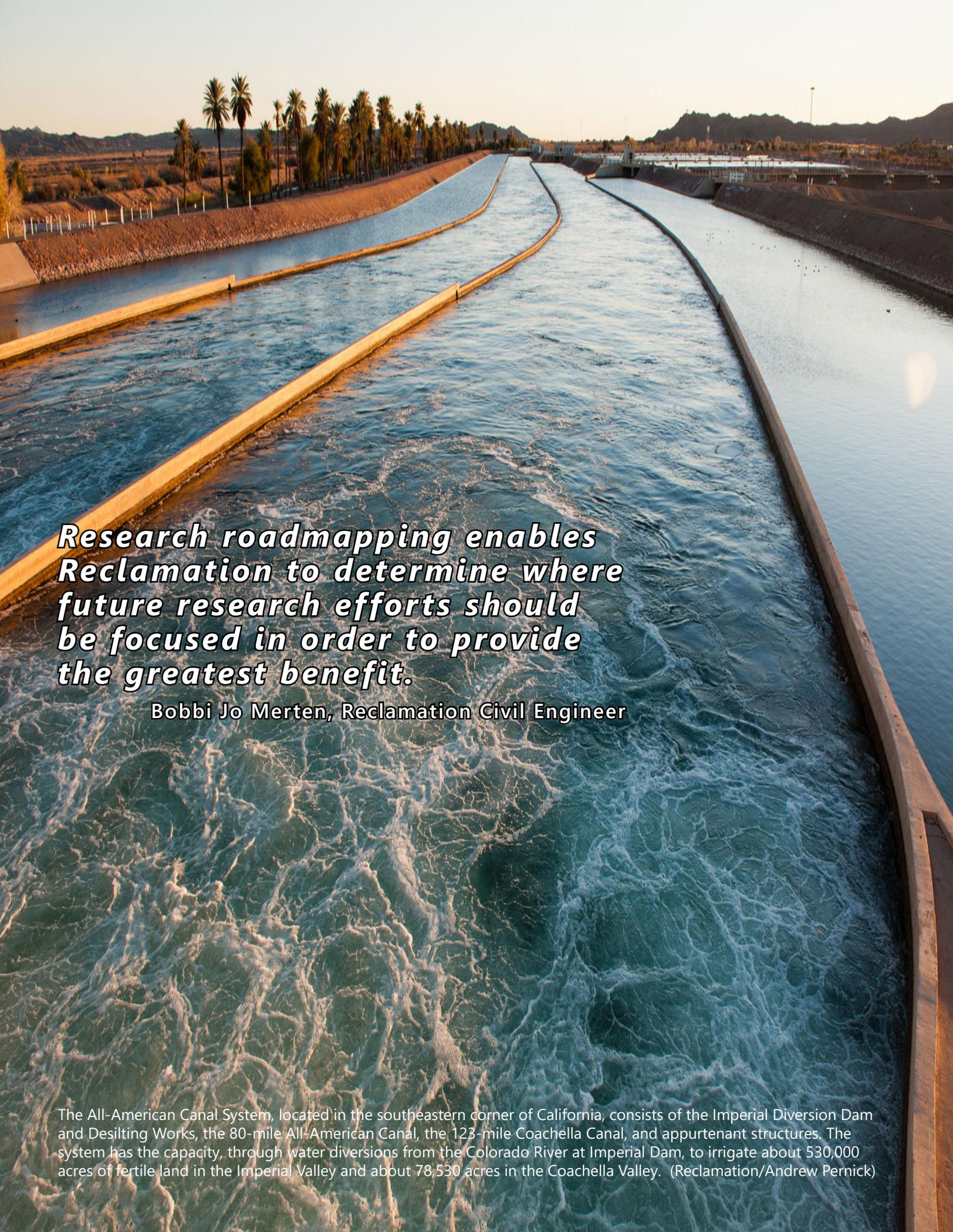
1. What are the common reasons for reduced service life, extraordinary maintenance, or failure of canal infrastructure components?
2. What mitigation practices are currently used by Reclamation to address these failures or extend the working life of the infrastructure components?
3. What additional tools, measures, and technology, or improvements in existing technology, might allow us to extend the service life for all reserved and constructed canal infrastructure components?

The purpose of [Research Priorities to Enhance Canal Infrastructure Sustainability](#) is to fill gaps in Reclamation's current toolbox to extend the useful life of critical infrastructure. Reclamation field and Denver Office personnel generated the data used in this roadmapping process. A team of subject matter experts completed the roadmap and prioritized the identified research needs. The canal infrastructure research roadmap describes the research need by identifying adverse outcomes, causes, current mitigation practices, and outstanding needs for tools, technology, etc.

The highest priority need statements relate to: canal seepage technologies; canal linings, repair and underwater placement; prevention and control of animal burrows and vegetation, and lightweight pipe performance issues.

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<https://www.usbr.gov/research/st/roadmaps/Canals.pdf>



Research roadmapping enables Reclamation to determine where future research efforts should be focused in order to provide the greatest benefit.

Bobbi Jo Merten, Reclamation Civil Engineer

The All-American Canal System, located in the southeastern corner of California, consists of the Imperial Diversion Dam and Desilting Works, the 80-mile All-American Canal, the 123-mile Coachella Canal, and appurtenant structures. The system has the capacity, through water diversions from the Colorado River at Imperial Dam, to irrigate about 530,000 acres of fertile land in the Imperial Valley and about 78,530 acres in the Coachella Valley. (Reclamation/Andrew Pernick)

Key Perspectives

A Canal Seepage Assessment Framework for Improving Water Resource Management and Safety

Canal seepage losses affect the ability of water conveyance structures to maximize efficiency and can be a precursor to canal failure. Identification and quantification of canal seepage out of unlined canals is a complex interaction affected by: geology, canal stage, operations, embankment geometry, siltation, animal burrows, structures, and other physical characteristics. Seepage out of unlined canals can be coarsely estimated using a mass balance-type approach (water in minus water out with the difference assumed to be a combination of seepage and evapotranspiration). More sophisticated methods are used in some instances but are typically limited efforts aimed at quantifying seepage in a specific location.

What is Canal Seepage?

Seepage is generally broken out into two categories: diffuse and concentrated seepage. Diffuse seepage is relatively constant discharge over a given area. It typically occurs in homogeneous conditions where the amount of water flowing into the subsurface is controlled by soil permeability and canal stage.

Concentrated seepage is preferentially focused into small sources. It usually occurs in areas of heterogeneous conditions where water flows into bedrock fractures, rodent burrows, or other pre-existing discrete flow-paths. Concentrated seepage can develop in the advent of sudden or excessive increases in hydraulic gradient which can lead to heaving, cracking, and development of backward erosion piping flow-paths.



Reclamation researchers install temperature rods for measuring diffuse seepage using heat as a tracer technology. (Reclamation/Evan Lindenbach)

Detecting, Quantifying, and Modeling Canal Seepage

S&T Project 19144 research developed an assessment framework for seepage detection, quantification and modeling with the goal of increasing the efficiency of water delivery systems and improving canal safety. This framework is intended for assessing canal seepage losses that are not influenced by the groundwater table or hydraulically disconnected canal systems. Canals that are hydraulically connected to groundwater will need additional equipment and monitoring. Development of a roadmap for a full canal seepage model with order of magnitude costs and a decision matrix for which techniques to use in what circumstances is in active development.

When completing a seepage analysis, it is advised to re-evaluate the knowledge gained at each step before moving forward to ensure overall understanding. Data from the various monitoring methods should be collected and incorporated to develop seepage estimates for the entire length of the canal based on canal stage and/or flow. This will involve combing sections of the canal based on seepage type and/or quantity.

Canal Seepage Assessment Framework



1 Perform a literature review and desktop level reconnaissance.

Evaluate geology, canal as-builts, known seepage locations, phreatophytes, past and ongoing canal maintenance operations, etc. to identify suspect regions. Use this information along with visually investigating aerial imagery to identify areas more likely to be susceptible to diffuse versus concentrated seepage.



2 Develop a conceptual model.

Incorporate geology, canal length, geometry, area, sediment heterogeneity, clogging, scour, sedimentation, type of seepage by location (diffuse vs point-source), variability of canal stage, connectivity to groundwater, and groundwater pumping.



3 Investigate with surface-based geophysics in a phased effort.

The first phase would involve rapid reconnaissance-type geophysical profiling techniques (e.g., electromagnetic and magnetic surveying), and the second phase would involve more detailed geophysical imaging techniques (e.g., electrical resistivity tomography) at select target seepage areas/features. Surveys should be performed during both de-watered and water-up conditions.



4 Calculate Normalized Difference Vegetation Index (NDVI).

Acquire any existing satellite-based remote sensing data for use in calculating NDVI remote sensing data products for use in further analysis with geophysical data profiles.



5 Collect Thermal Infrared (IR) and Near Infrared (NIR) data.

Fly the canal with an Unmanned Aerial System (UAS) to develop high-resolution NDVI images and utilize IR and NIR. This will help identify thermal anomalies associated with near-surface voids and seepage zones associated with increased saturation of downstream surface soils and any standing surface water. Perform survey at least once per irrigation season, ideally twice: once during dewatered conditions, and once during watered-up conditions.



6 Utilize satellite-based L-band Synthetic-Aperture Radar (SAR) remote sensing technology.

Evaluate geology, canal as-builts, known seepage locations, phreatophytes, past and ongoing canal maintenance operations, etc. to identify suspect regions. Use this information along with visually investigating aerial imagery to identify areas more likely to be susceptible to diffuse versus concentrated seepage.



7 Identify zones of diffuse seepage.

Measure flow from identified seeps directly with flumes and monitor regularly for at least one irrigation season. For zones of diffuse seepage, install temperature probes and use heat as a tracer technology.



8 Monitor for at least one irrigation season.

Develop 2-D transects heat and flow transport models for diffuse seepage estimation. Quantify soil hydraulic conductivity from laboratory samples obtained during equipment installation, calibrate the models using laboratory data and field measurements.



9 Identify concentrated seepage.

Evaluate geology, canal as-builts, known seepage locations, phreatophytes, past and ongoing canal maintenance operations, etc., to identify suspect regions. Use this information along with visually investigating aerial imagery to identify areas more likely to be susceptible to diffuse versus concentrated seepage.



10 Develop and calibrate 2-D and/or 3-D model(s).

The model(s) should include geological profiles for the entire study site and be calibrated with hydraulic conductivities and volumetric water contents quantified from SAR and laboratory data.

Background research (steps 1 and 2) should be completed prior to any of the following steps. Ideally, geophysical and remote sensing techniques (steps 3 through 6) are performed for the initial irrigation season. The second irrigation season would then include direct seepage measurements (steps 7 through 9) along with another round of targeted geophysics and remote sensing (steps 3 through 6) to generate a detailed data set. This process will minimize data gaps as all types of seepage and variations in subsurface conditions can be captured. Geophysical and remote sensing techniques (steps 3 through 6) can be performed concurrently with direct seepage measurements (steps 7 through 9) with the understanding that there may be data gaps due to unrecognized subsurface conditions.

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Current Research

Rapid Geophysical Profiling for Canal Embankment and Levee Health Assessment and Seepage Detection

Problem

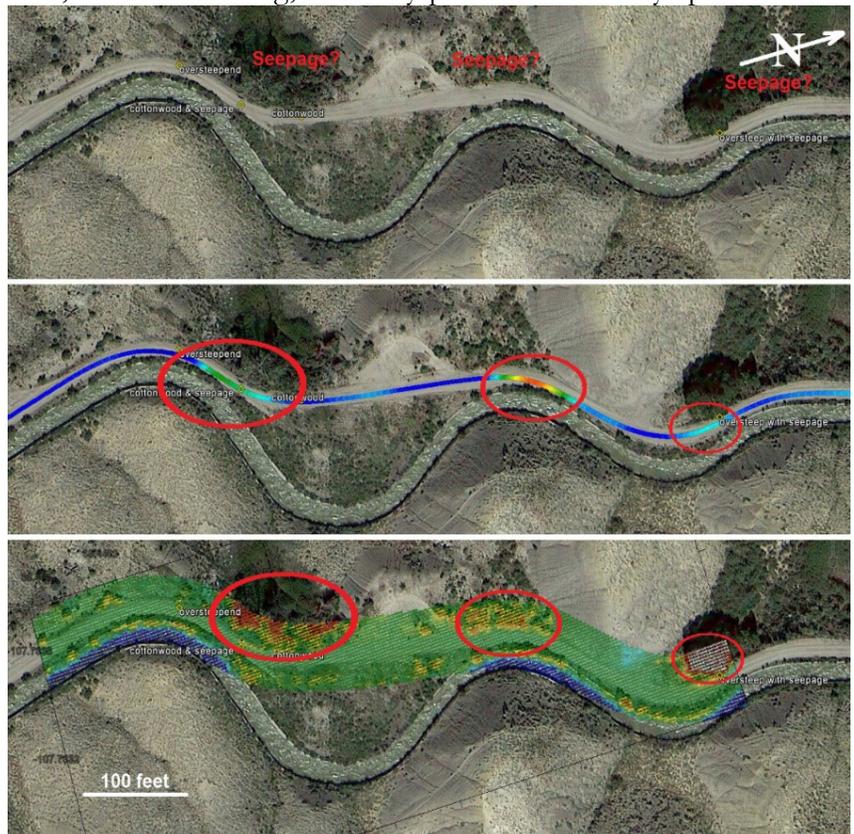
Across the United States, canals and levees comprise extensive systems of critical infrastructure that pose several practical and technical challenges to adequately assess health, performance, and maintenance needs. Visual inspections are limited to line-of-site observations, and are a subjective process that is vulnerable to human error and bias. More focused investigation techniques such as targeted geophysical surveys or drilling operations are oftentimes very expensive, time consuming, and only provide extremely sparse data coverage that can easily miss unknown problems.

To exacerbate the complexity of inspecting canals, many of these structures are reaching or have surpassed their initial design life and performance-related issues are increasingly common. In addition to increased frequency and risk of sudden embankment failures, cumulative water conveyance losses from distributed seepage along canals can have significant water budget and economic impacts.

There is a growing need for rapid surveying and inspections technologies to improve comprehensive reconnaissance-level characterization of canal systems. Remote sensing and rapid geophysical profiling (a suite of non-destructive testing and subsurface imaging techniques) can provide the newest suite of surveying and inspection tools for rapid characterization and monitoring of canal health.

Solution

Reclamation's Science and Technology Program funded research was conducted in fiscal years 2016 through 2018 to develop and test new approaches to rapid detection and mapping of canal seepage. A promising new approach combines satellite-based remote sensing imagery data and rapid surface-based geophysical profiling data with a semi-automated data fusion, analysis, and data interpretation workflow. The new approach involves the use of Normalized Difference Vegetative Index (NDVI) remote sensing data images,



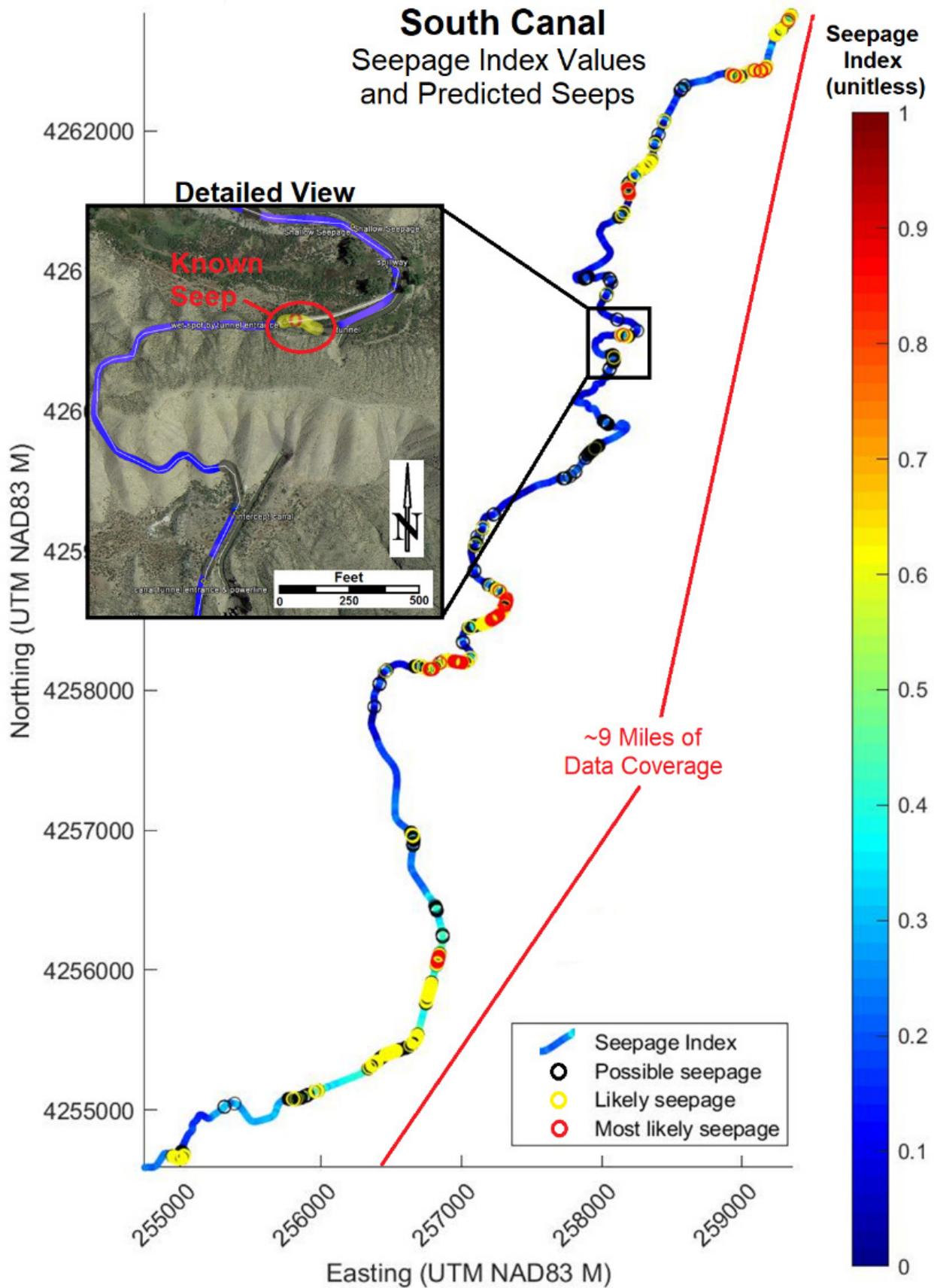
An example showing geophysical profiling anomalies and elevated NDVI values at known and suspected canal seepage locations. These data can be utilized to detect, map, and better characterize seepage losses. (Reclamation/Justin Rittgers)

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Calculated Seepage Index values and predicted seepage locations along ~ 9 miles of South Canal, Colorado. The inset detailed view provides an example of successful detection at a known seepage location, and demonstrates one of the end-user data products of the workflow: Google Earth™ overlays of results. (Reclamation/Justin Rittgers)

combined with ground-based frequency-domain electromagnetic (FDEM) and magnetic gradiometry profiling surveys conducted along canal embankments.

Several commercially available geophysical systems were evaluated for their functionality and sensitivity to lateral changes in bulk electrical conductivity associated with canal seepage. An inexpensive and towable non-magnetic cart was designed and fabricated to enable rapid (i.e., 5-10 mph) data collection along embankment crest roads, enabling tens of miles of continuous profiling data to be collected in a single day.

The collected data are then combined to develop a new “Seepage Index” data attribute along inspected canals that shows areas of likely seepage. This research investigated to use of machine learning algorithms to build the seepage index. Results show great promise for further automation of data interpretation and seepage detection using the developed approaches.



Results

This research involved partnerships with Reclamation’s Western Colorado and Provo Utah Area

Offices, where a total of nearly 30 miles of data coverage was acquired along three separate canals systems: South Canal and Government Highline Canal near Grand Junction, Colorado, and Strawberry Highline

Non-magnetic cart configured with tethered and gimbaled segments for carrying long (~30ft) FDEM systems. The platform is versatile enough to handle sharp curves and rough terrain at speed and can be easily repaired in the field. (Reclamation/Justin Rittgers)

| Economic Impacts of Rapid Geophysical Profiling (RGP) S&T Project 9918 | | | | |
|---|--------------------|----------------|--------------------|-----------------|
| Discount rate (FY 2020 Planning Rate) | 2.75% | | | |
| Strawberry Highline Canal (SHLC) miles | 17.5 | | | |
| Approximate urban canals nationwide | 10,000 | | | |
| Annualized savings due to RGP based on 120yr period of analysis (POA) and derived annuity factor | 2018 \$ | | 2020 \$ | |
| | \$105,163 | | \$111,026 | |
| Federal investment in RGP research project (COST) | \$295,000 | | \$311,448 | |
| Economic Impacts Summary | 10-year POA | | 40-year POA | |
| | 2018 \$ | 2020 \$ | 2018 \$ | 2020 \$ |
| Present value of savings at SHLC (BENEFIT) | \$908,616 | \$959,273 | \$2,532,125 | \$2,673,295 |
| Net return of federal investment at SHLC | \$613,616 | \$647,825 | \$2,237,125 | \$2,361,847 |
| ROI to federal dollars | 208% | 208% | 758% | 758% |
| BCR to federal dollars | 3.1 | 3.1 | 8.6 | 8.6 |
| Net return per mile at SHLC | \$35,064 | \$37,019 | \$127,836 | \$134,963 |
| Net return across all U.S. urban canal miles | \$350,640,000 | \$370,190,000 | \$1,278,360,000 | \$1,349,630,000 |
| <i>Upon implementation of RGP, the longer the POA, the higher the net benefit - and thus ROI - though at a decreasing rate due to the time-value of money. (Reclamation/Todd Gaston, Justin Rittgers)</i> | | | | |

Canal near Provo, Utah. These partnerships and resulting data enabled the initial testing and development of robust and semi-automated data processing and analysis workflows. Results from developing the new Seepage Index data attribute and applying machine learning to predict seepage locations were validated by comparison with known and observed seepage areas/features along each canal. These results also helped to flag previously unidentified locations that are likely experiencing seepage losses along these structures.

An additional outcome of this research is the ability to also rapidly detect and map subsurface metal, such as abandoned conduits or unauthorized metallic perforations. Lastly, the use of the cart platform can be easily augmented to support additional survey types and applications, including 2D mapping of shallow alluvial depositional patterns (i.e., mapping clays versus sands) or

the use of ground penetrating radar for non-metallic conduit or utility locating and for identifying open air-filled voids or animal burrows.

Following completion of this research, the project was selected by S&T for a Return on Investment (ROI) analysis carried out by engineering economists at TSC. By utilizing estimated and known costs and occurrence intervals of failure events using statistics of recent performance data from one of the canal segments studied, the results of this ROI analysis normalized on a per-canal-mile basis over the next 120 years (see table, previous page).

Current Applications

The new seepage detection workflow is currently being utilized to help inform a related S&T research project being conducted along a reach of the Truckee Canal near Fernley, Nevada. S&T researchers (in partnership with Reclamation's Lahontan Basin Area Office (LBAO), NASA, and the USGS) are investigating the use of interferometric synthetic aperture radar (INSAR) satellite remote sensing data as an additional tool for seepage detection and time-lapse condition monitoring of seeps along canals and levees.

The seepage detection workflow described here is being used to help verify seepage conditions along the Truckee Canal. In addition to the results of this new workflow, known seepage and non-seepage segments will be used as ground-truthing to help evaluate the effectiveness and limitations of INSAR for seepage characterization. The FDEM data is being used to estimate depth to seepage and geologic layers of interest. The end-goal is to utilize this screening-level information to help evaluate if INSAR analysis can be used not only to detect seepage, but to go as far as estimating average hydraulic conductivity of materials between the canal and a given seepage area. A similar but unrelated application of the new FDEM data

collection and processing workflow is being planned for helping to inform subsurface alluvial geology for the San Joaquin River Restoration Project (SJRRP). Approximately 40 miles of data collection and model production is planned for the SJRRP effort.

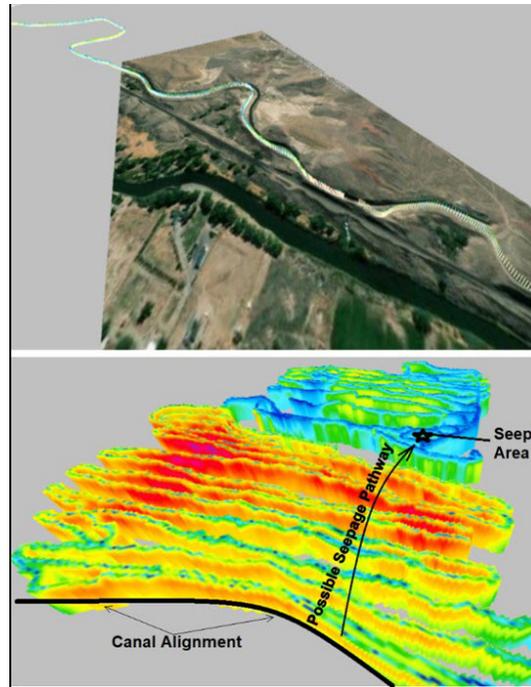
Future Plans

Future efforts will focus on continuation and development of new partnerships for further implementation and improvement of this developed seepage detection workflow. Partnerships with

regional and area offices within Reclamation will help to further advance the developed workflow. New and ongoing cooperative partnerships with stakeholders will help provide verified seepage and performance data for use as training and validation—further solidifying the method. Information learned in future projects will also help to further evaluate integration of additional data types and optimize analysis workflows. Moving forward, data types of upmost interest for future integration into the workflow include 1) embankment prism geometry attributes, 2) digital geologic maps/soil-type maps, and 3) hyper-spectral remote sensing data that can be used to help classify surficial soil types along canals and levees of interest. Future partnerships will also provide the added-value and direct benefit to partners of obtaining insightful data coverage along embankments to help

inform subsequent field characterization activities and O&M decisions.

Finally, future work will include an effort to integrate the various approaches and steps of seepage detection, canal health assessment, and health monitoring into a unified recommended workflow. This overall workflow will need ongoing updating and refining to incorporate new technologies and information as they become available.



Examples of modeled subsurface conductivity from FDEM data: a continuous 2D "ribbon" conductivity model reveals subsurface geology and seepage along the length of the Truckee Canal (top), and a 3D model showing complex subsurface patterns beneath a gridded survey at a specific seepage area of interest. (Reclamation/Justin Rittgers)

Detecting Seepage in Canals using Satellite Remote Sensing

Problem

Reclamation owns tens of thousands of miles of in-service water conveyance. Many of these canal systems show signs of aging and disrepair and extensive seepage. The consequences of canal failures within urban corridors are constantly increasing due to urban encroachment on these water conveyance structures. In addition to the problem of increased risk related to canal embankment failures, concentrated and distributed seepage poses a major challenge to water conservation due to significant water conveyance system losses.

Solution

S&T Project 19258 research was funded to study Synthetic-Aperture Radar (SAR) satellite remote sensing technology. The research encompassed using 10-m full resolution and 30-m multi-looked data to detect soil moisture content and time-lapse fluctuations in concentrated and distributed seepage. SAR satellite remote sensing technology aids in effective detection of seepage loss areas on a wide scale allowing for a rapid evaluation/monitoring of canal embankment systems, and efficient cost saving to cover nationwide canal sites.



Truckee Canal in winter. (Reclamation/Lahontan Basin Area Office)

This technique could lead to the ability for Reclamation to: (1) quickly and effectively identify previously unknown seepage areas on a system-wide or even nation-wide scale, (2) monitor known seepage areas for changes, (3) help to quantify system-wide water conveyance losses and identify priority sections for focused maintenance efforts, (4) differentiate between suspected seepage and natural groundwater drainage phenomena not related to canal water losses, (5) evaluate canal liner performance based on pre/post installation seepage levels, (6) evaluate canal damage repair and other proactive maintenance

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activities based on pre/post seepage conditions, and (7) identify changes in seepage following standard canal dredging activities, which have occasionally been suspected of initiating or exacerbating seepage losses.

Approach

Satellite-based radar has better capability than optical/thermal infrared in detecting wetness under vegetation and topsoil. There are three key practical properties necessary to monitor canal seepage remotely: spatial resolution, temporal resolution, and spatial coverage. Previous satellite radar missions lacked at least one of the key practical properties to properly monitor canal seepage. These practical limits are now obtainable using C-band (5.3 GHz) Sentinel-1 data since its launch in 2015. ALOS-1 and -2 satellite data operating at L-band are available from 2006 through 2011 and 2014 through present, respectively. Future radar missions, such as NASA-ISRO SAR (NISAR) operating at L-band are expected to have even better penetration through vegetation and soil.



Truckee Canal in autumn near Fernley, Nevada. (Reclamation/Lahontan Basin Area Office)

distributions, 2) conducting time-lapse analyses for temporal change detection on a per-satellite-image-pixel basis, and 3) identifying spatio-temporal changes following operations and maintenance events along canals (e.g., watering-up of a canal system, or pre/post embankment lining or repair efforts), in order to help evaluate changes in performance and hydrologic conditions along the embankment.

Pilot Study

The Truckee Canal is an approximately 31.2-mile irrigation canal, beginning at Derby Dam on the Truckee River and ending at Lahontan Reservoir on the Carson River. Approximately 26 miles of the Truckee Canal is lined with earthen embankments averaging 20 feet wide and 13 feet high. A year-long time-series of Sentinel SAR data for 2017 was obtained and analyzed. Sentinel-1 satellite data was used to evaluate the feasibility and value of using SAR satellite remote sensing technology to detect soil moisture content and time-lapse fluctuations related to seepage phenomena at the Truckee Canal. The spatial domain of the current pilot study at the Truckee Canal is shown in the figure on the next page.

Sentinel-1 was launched in 2015. By late 2016, the U.S. Western Region was sampled at a regular 12-day interval with the interferometric wide-swath mode offering the spatial resolution of $\sim 10\text{m}$ over the $\sim 300\text{km}$ swath. The ground-range detected (GRD) data were spatially multi-looked to reduce speckle noise. The models were calibrated and validated using ground survey data for 25 different locations.

In this case study, we tested the spatial and temporal resolution of Sentinel-1 data to estimate seepage. The time-series of radar backscattering coefficients for selected known seepage sites are shown in Figure 1 (b). The most prominent features are the 6 peaks around day 180. These peaks are deemed to be correct representation of seepage,

The SAR data at 10-m spatial resolution estimates average volumetric water content (VWC) within approximately 50-100cm (1.6-3.28 feet) or less of the subsurface soils. Monitoring VWC of soil near canals allows for estimate of canal seepage and can be compared with field/lab test results.

The L-band SAR could provide an opportunity to more detailed analysis of canal seepage by: 1) cataloging the spatial variations in SAR satellite images related to shallow ($\leq 1\text{m}$ below ground surface) soil moisture

considering that in 2017, the Truckee Canal watered up on April 1 (day 90 in the plot) and it took about 60 days for seeps to develop in the Truckee sites. Peak VWC occurred about 60 days following water up in the Truckee sites. A successful example of the spatial analysis to locate the seepage is shown in Figure 1 (c). The temporal difference of Sentinel images was taken before and after the period when seepage was expected based on canal stage. Each of the two images was averaged temporally to reduce speckle. The dark pattern in the figures matches the known seepage locations. These results indicate that current seepage locations can be identified from the satellite imageries corresponding to the known seepage locations.

The temporal detection method identified 10 seepage events at the correct time of the year. Six of the ten seepage locations had strong correlations while the other four were of small intensity. The spatial analysis located seven potential seepage

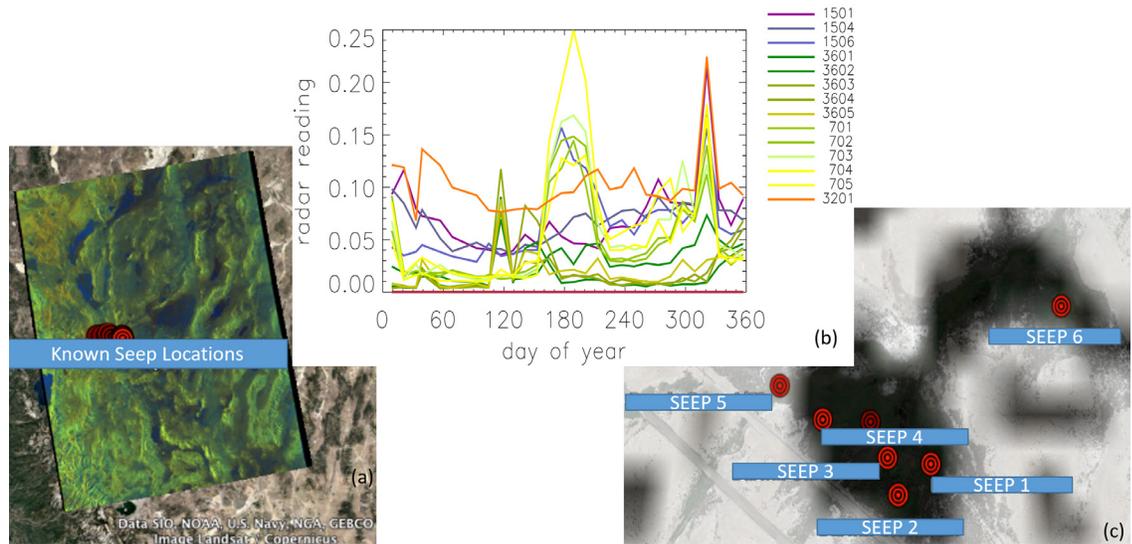
locations. Periodically collected SAR data and the time-lapse analysis results provide valuable information within a short time period to detect seepage. This initial proof-of-concept effort using the Truckee Canal as a case study shows that the SAR approach is feasible for detecting seepage.

Summary

This research is an ongoing project at the Truckee Canal site. Future works that can be performed includes: (1) Increasing the temporal imaging frequency two-

fold by examining soil moisture time-series followed by its retrieval; (2) having researchers quantify volumetric water content of subsurface soils at select locations along the canal, including at known seep areas via field measurements if existing data/instrumentation is not already available for the necessary sites; (3) collecting subsurface soil samples at select locations for subsequent detailed lab testing of geotechnical and hydrogeological properties; (4) installing piezometer and observation wells perpendicular at some of the known seepage locations to help inform subsequent research efforts aimed at developing and calibrating groundwater models; (5) analyzing multiple-year L-band and C-band satellite image data archived from the ALOS-1(L-band, 46-day repeat) and Sentinel-1A/B (C-band, 6- and 12-day repeat) satellites; (6) generating co-registered stacks of single-look complex (SLC) data to further analyze the phase and amplitude for seepage detection methods (Fattahi et al., 2017); (7) detecting surface displacement on the order of a few centimeters using interferometric analysis; and (8) comparing coherence changes through time. The stacks will be at the full resolution of the radar (~10m ground pixel spacing) and the temporal resolution is determined by the acquisition schedule of the satellite imagery.

This new enhanced seepage detection approach using the C- and L-band SAR satellite remote sensing technology will provide a technique to quantify potential seepage losses for more rapid and global management of canal embankments. More specifically, this research will provide enhanced seepage detection and characterization approaches to the Reclamation area offices and other agencies, directly help Reclamation manage water resources efficiently, and potentially be applicable to other earthen embankment sites and structures in order to identify and prioritize potential repair locations to promote healthy water conveyance and storage infrastructure.



SAR data processing: (a) Boundary of Sentinel-1 data at Truckee Canal study domain near Fernley, Nevada (~300km wide and 500km long); (b) Time series of radar backscattering coefficients at selected known seepage sites for 2017; and (c) Overlay of known seepage location (red) on a binary form (significant change in dark or negligible change in transparent) with the background of the Google optical map. (Reclamation/Jong Kang)

Using Heat as a Tracer to Estimate Seepage Losses and Improve Water Operations

Problem

Seepage losses from irrigation canals poses major challenges to water managers. Seepage losses result in inefficiencies in water delivery and cause more water than is needed by farmers to be diverted to meet required demands. Reclamation in partnership with the U.S. Geological Survey (USGS) aims to assist the agency's effort to better conserve and manage water supplies to meet competing water needs under a variable and changing climate.

Solution

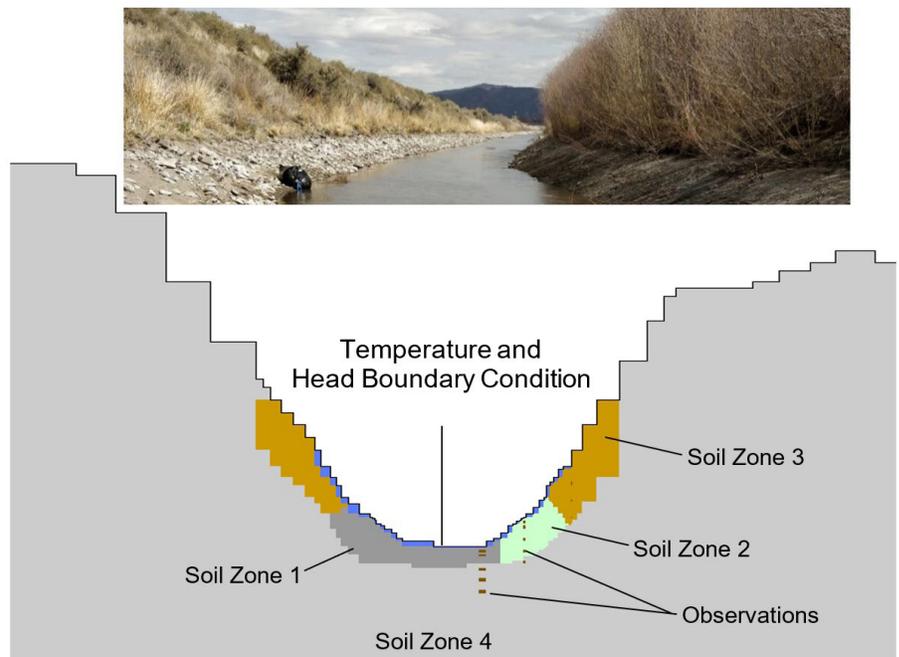
The goals of this research project funded through S&T Project 19144 were to quantify seepage losses along sections of the Truckee Canal in Nevada to better understand the spatial and temporal variability of seepage losses, characterize discharge at seep locations, and develop regressions relating canal stage to seepage. This study will help delineate reaches of higher seepage loss and determine seepage rates to improve accounting, and provide information needed to mitigate loss of efficiency.

Sediment temperature measured continuously has been used in groundwater flow models to estimate seepage rates with dynamically changing surface flow conditions. The usefulness of temperature data for canal seepage investigations has been recently demonstrated in smaller scale irrigation canals. Part of the success of this approach was the ability to estimate losses for multiple irrigation seasons, while incorporating the dynamic behavior of canal operations and

groundwater pumping on seepage rates. Seepage investigations have benefited from the use of a newly developed temperature probe designed specifically for heat as a tracer approach. The main advantages of this device are the simple low-profile design, open-source software, and accuracy of measurements.

Approach

The use of heat as a tracer for estimating canal seepage loss involves monitoring sediment temperatures at multiple depths below the canal and variations in canal stage. The selected monitoring approach was designed



Transect representation of soil zones, observations, and boundary conditions used for seepage models. (U.S. Geological Survey/Ramon Naranjo)

to estimate vertical and horizontal seepage losses and account for subsurface soil heterogeneity. At each transect two temperature probes were installed in the bottom of the channel (see image above). Additionally, piezometers were installed and instrumented with

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<https://www.usbr.gov/research/projects/detail.cfm?id=19144>

temperature sensors in the canal bank. The spatial variability of seepage rates was assessed by monitoring temperature at 15 to 20 locations within each of the 20 transects. Data was recorded at 0.5-hour intervals from March to November during the 2018-19 irrigation seasons.

At each transect, thermal and hydraulic properties, canal cross-section geometry, and stage are needed as inputs to numerical model VS2DH. The subsurface soils are idealized into soil zones based on lithology determined from soil cores that provided visual and laboratory characterization of the soil profile (Fig. 1-2). Soil testing was performed to determine fitting parameters for the van Genuchten infiltration models used by VS2DH (Fig. 2b). Because seepage models are highly sensitive to thermal properties, field measurements of thermal conductivity were made monthly using a hand-held device (Fig. 2c).

The parameter-estimation model, PEST++ (Welter and others, 2015) was applied to calibrate the model by adjusting hydraulic and thermal properties until model simulations were within agreement of the observed temperatures. Assessment of calibrated parameters and seepage estimates were completed through model sensitivity and uncertainty analysis.

Future Plans

Work is nearly complete on providing stage-seepage regressions for all transects in the Truckee Canal. Data collected during the 2018 irrigation season was used for model calibration and data from 2019 will be used as model verification. Evaluating model performance



Multi-depth temperature probe (a), soil-core samples (b) and thermal conductivity sensor (c) used to parameterize seepage models. (U.S. Geological Survey/Ramon Naranjo)

for multiple irrigation seasons is necessary to assess whether calibrated parameters did not change over time.

The tools used for estimating seepage losses allow managers to optimize water management and better conserve existing water supplies fostering ecological and economic benefits. As a result of this research, Reclamation will have improved knowledge of how seepage rates vary over time and space. The methodology used in this study can be applied to other canal systems managed by Reclamation to improve seepage estimates in canal operations and provide managers the information they need to improve delivery efficiencies.

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