RECLAMATION

Managing Water in the West

Technical Memorandum No. MERL-2014-54

Research Priorities to Enhance Canal Infrastructure Sustainability

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Materials Engineering and Research Laboratory
Denver, Colorado

September 2014

MISSION STATEMENTS

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BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Materials Engineering and Research Laboratory, 86-68180

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Research Priorities to Enhance Canal Infrastructure Sustainability

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EXECUTIVE SUMMARY

Addressing the needs of aging infrastructure is critical to system reliability [1]. Research roadmapping enables us to determine where future research efforts should be focused in order to provide the greatest benefit. In this report, we explore the existing needs of aging infrastructure and identify key research needs, establishing a framework for research roadmapping (mapping). The canals infrastructure draft roadmap is attached, which provides a comprehensive description of the research need, including the adverse outcome, currently used mitigation practices, and the outstanding needs for tools, technology, etc. The intent of this information is to provide a thorough explanation of the research need to potential researchers in this area. The highest priority need statements are listed below:

- Effective canal seepage detection methods or technologies for use by engineers or field staff to more clearly define seepage paths
- Concrete canal lining
    - Underwater canal lining repair materials and methods for cracked, buckled, or bulged linings (underwater crack sealants, grouts, etc.)
    - Underwater canal panel placement material or method
- Animal burrows
    - Tools to control or prevent animal burrowing in canals (nonhazardous)
    - Effective methods for repair of animal burrows in canals
- Vegetation
    - Tools to control or prevent woody vegetation in canals (nonhazardous)
    - Tools to control or prevent waterborne vegetation in canals (algae blooms, watergrass, etc.) (nonhazardous)
- Improved, less expensive canal lining, cover, and repair materials and methods (which districts can install themselves – low tech)

- Resolve identified performance issues for lightweight pipe as an alternative to reinforced concrete pipe through embankments (see Federal Emergency Management Agency [FEMA] report [2])

- Methods and materials for underwater placement of canal linings

The forthcoming comprehensive research map incorporates these research needs identified for canals in addition to the remainder of the Bureau of Reclamation's infrastructure components.

INTRODUCTION

The Bureau of Reclamation's (Reclamation) Research and Development Office enacted several research roadmapping (mapping) endeavors in order to strategically identify the organization's evolving scientific and engineering research needs. As an example, "Addressing Climate Change in Long-Term Water Resources Planning and Management, User Needs for Improving Tools and Information" addressed interagency impacts of climate change [3]. In addition, the "Desalination and Water Purification Technology Roadmap – A Report of the Executive Committee" identified opportunities for the growing water supply challenges [4]. Ecohydraulics mapping is ongoing.

The needs of Reclamation's aging infrastructure is addressed under the current research project. The "Bureau of Reclamation Asset Management Plan" reiterates that this is "central to the mission objectives of operation & maintenance (O&M) projects" [1]. Therefore, these three research questions (RQ) are of key interest:

RQ #1: What are the common reasons for reduced service life, extraordinary maintenance, or failure of Reclamation's infrastructure components?

RQ #2: What mitigation practices are currently used by Reclamation to address these failures or extend the working life of the infrastructure components?

RQ #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 Reclamation infrastructure components?

Table 1 provides Reclamation's mission-critical infrastructure (or assets) as described by Policy and Administration (P&A). Mission critical is defined as, "a facility or piece of equipment that if unavailable or inoperable, would substantially detract from the achievement of Reclamation's business objectives" [1]. The use of these component categories allows us to focus on each infrastructure type separately. Furthermore, the answers to RQ #1 are more apparent for their corresponding major components.

A parallel project, under which we are evaluating powerplant infrastructure, is ongoing under Project Manager Erin Foraker (Renewable Energy Research Coordinator, Reclamation). The focus of this project is on aging infrastructure from the perspective of its engineering disciplines. Therefore, the categories listed as "Other" in table 1 lie outside the scope of the existing framework; these categories may be approached by similar means at a later date.

Table 1.—Reclamation mission-critical assets

Category	Components
Dams	Dams, spillways, outlet works, gates (for dam operation)
Canals	Canals, laterals, reservoirs, gates, crane/lifts, trash rack structures, siphons, diversion dams, flow meters
Pipelines	Pipelines, surge tanks, associated components (with pipeline)
Powerplants	Gates, penstocks, turbines, excitation, generators, step-up transformer, auxiliaries, instrumentation and controls, unit breaker/switchgear, draft tubes
Pumping plants	Intake units, tanks, pump casings, motors, auxiliaries, instrumentation and control, discharge pipes
Other	Supervisory Control and Data acquisition (SCADA) systems, communication systems, associated land, etc.

RESEARCH METHOD

The "Research Roadmapping Method & Pilot Study" describes research method development [5]. A more thorough report of the finalized method is forthcoming [6]. The research roadmapping project proceeds in several phases. Table 2 provides the estimated timeline for the individual projects by fiscal year and quarter. The final step combines the draft roadmaps into a comprehensive document.

Table 2.—Roadmapping schedule

	FY13		FY14				FY15			
Category	3	4	1	2	3	4	1	2	3	4
Pipelines	Committee survey						Draft roadmap			
Pumping plants					Draft roadmap					
Canals				Draft roadmap					Combined research mapping	
Dams				Draft roadmap						

Figure 1 summarizes the roadmapping method. SurveyMonkey® provided a means for obtaining data for the three RQs. Subject matter experts, including Technical Service Center (TSC) engineers, P&A program analysts, and field office—regional, area, and facility—personnel contributed to these datasets.

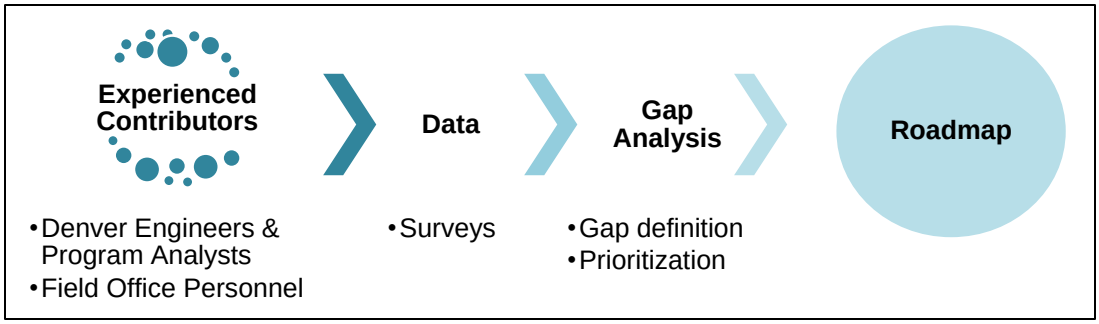

Figure 1.—Process for infrastructure sustainability roadmap.

The questionnaire data were collated, and similar responses were grouped together and coded. Some interpretation of responses was required. Each code is a summarized description of the statements made by respondents. These codes appear in the draft roadmap as "adverse outcomes" for RQ #1. In addition, these answers informed the development of the "causal analysis." Expert input from TSC engineers and P&A program analysts provided clarification and filled information gaps where appropriate. The final analysis of the roadmap included calculated statistics for "normalized frequency" and "average concern."

RQs #2 and #3 provided the "gap analysis" information. Again, TSC and P&A personnel critiqued the accuracy and completeness of the coded information.

Finally, the coded information for all three RQs aided in the development of the "research needs" for each adverse outcome. TSC and P&A personnel then scored the "gaps in existing tools" and "research needs." These two categories address the size of the gaps in existing tools and the value of anticipated research results, respectively.

This work resulted in four categories of quantitative information: frequency, concern, gaps in existing tools, and research needs. The respective rankings for these categories are 0–3, 0–3, 0–5, and 0–5. The four categories were summed, and the draft roadmap table was sorted from the highest to lowest score. The highest score represents the highest necessity for research.

TSC and P&A personnel evaluated the research needs for each adverse outcome and reduced the information to a short list of highest priority research needs.

RESULTS

Nineteen survey responses were included in the analysis. Denver personnel represented 26 percent of the survey respondents and included the following groups:

- Water Conveyance
- Asset Management
- Materials Engineering and Research Laboratory

The remaining 74 percent of the survey respondents represented field offices. The geospatial location of these personnel is critical to ensure that all of Reclamation's needs are included. For instance, climatic stresses (weather) varies greatly from region to region. Respondents hold offices in the following locations:

- Phoenix, Arizona
- Boise, Idaho
- Billings, Montana
- Sacramento, California
- Bend, Oregon
- Hermiston, Oregon

Attachment B provides the compiled survey results as the draft roadmap. This attachment includes the additional editing for accuracy and completeness provided by TSC and P&A personnel. Furthermore, it is prioritized based on the statistics for frequency (normalized:nrm) and concern (average:avg) as well as the rankings for sufficiency of current tools and research needs—provided by TSC and P&A personnel. The results were normalized or averaged so that all responses would be reflected in the scoring.

Table 3 provides the short list of highest priority research needs. These research need statements will be incorporated into the forthcoming comprehensive research roadmap for Reclamation's infrastructure. The goal is for researchers in these respective areas to develop and implement solutions. A process for instituting the ensuing research projects in progress.

Table 3.—Need statements for highest priority research needs

Effective canal seepage detection methods or technologies for use by engineers or field staff to more clearly define seepage paths
A) Underwater canal lining repair materials and methods for cracked, buckled, or bulged linings (underwater crack sealants, grouts, etc.) B) Underwater canal panel placement material or method
A) Tools to control or prevent animal burrowing in canals (nonhazardous) B) Effective methods for repair of animal burrows in canals
A) Tools to control or prevent woody vegetation in canals (nonhazardous) B) Tools to control or prevent waterborne vegetation in canals (algae blooms, watergrass, etc.) (nonhazardous)
Improved, less expensive canal lining, cover, and repair materials and methods (which districts can install themselves – low tech)
Resolve identified performance issues for lightweight pipe as an alternative to reinforced concrete pipe through embankments (see FEMA report [2])
Methods and materials for underwater placement of canal linings

REFERENCES

[1] "Bureau of Reclamation Asset Management Plan," Bureau of Reclamation, Policy and Administration, Fiscal Year 2011, September 2012.

[2] "Plastic Pipe used in Embankment Dams: Best Practices for Design, Construction, Problem Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair," Federal Emergency Management Agency, Technical Manual, November 2007.

[3] Brekke, L.D., "Addressing Climate Change in Long-Term Water Resources Planning and Management, User Needs for Improving Tools and Information," Bureau of Reclamation, Science and Technology Program, Technical Report, January 2011.

[4] "Desalination and Water Purification Technology Roadmap – A Report of the Executive Committee," Bureau of Reclamation, Desalination & Water Purification Research & Development Program, Report #95, January 2003.

[5] Merten, B., "Research Roadmapping Method & Pilot Study," Bureau of Reclamation, Technical Memorandum No. MERL-2014-53, September 2014.

[6] Merten, B., "Research Roadmapping Framework to Enhance Infrastructure Sustainability," in preparation.

ATTACHMENT A

Canals Questionnaire

The Technical Service Center (TSC), in conjunction with the Research and Development Office, is preparing a research roadmap to identify ongoing research needs. The attached survey allows us to take a closer look at Reclamation's infrastructure from its subset of "Canals" and related features. This information will be used to determine where future research efforts should focus, with a goal of providing the greatest benefit to the organization as a whole.

You were selected for this questionnaire based on your knowledge and experience. We appreciate your time and hope that you will complete it by March 21, 2014. It contains 7 topic areas (Canal Subgrade, Canal Linings, Diversion Dams, Check Structures, Gates/Turnouts, Siphons, Other) with 5 questions each. The 2 additional questions determine contact information (in case an answer requires clarification) and feedback, for a total of 37 questions. The approximate time to complete is 1 hour. You do not have to fill-in all boxes if you feel no additional issues exist. You are free to navigate backward/ foreword, edit responses, stop/re-start later, discuss answers with colleagues, etc. Press "done" to submit your completed questionnaire. Your careful and well-constructed insight is appreciated.

Thank you in advance for your time. For questions or concerns, please contact me at 303-445-2397 or send me an email at jswihart@usbr.gov. For technical difficulties, contact Bobbi Jo Merten, 303-445-2380 or bmerten@usbr.gov.

Thanks

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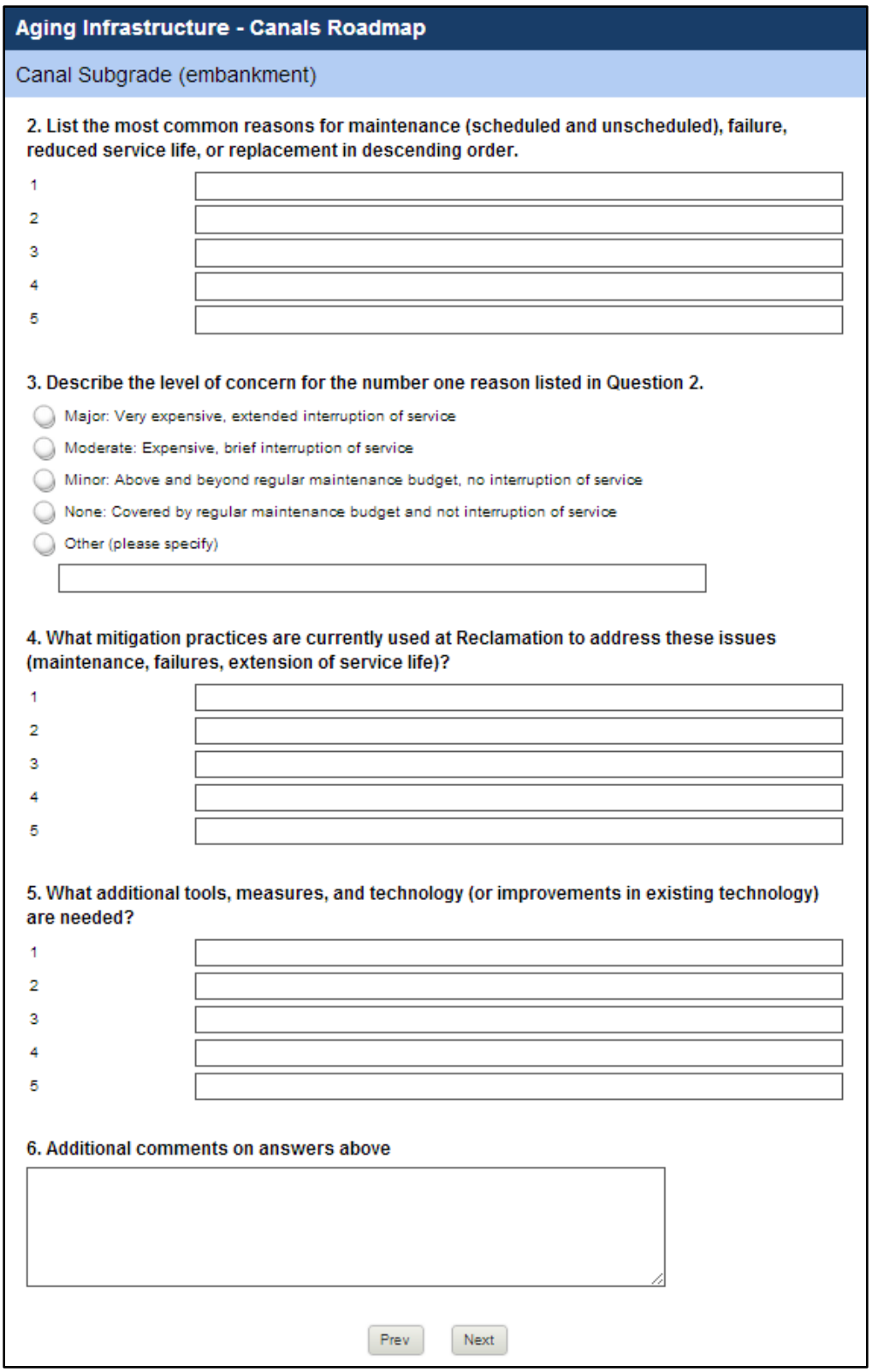

Figure A1.—Canal questionnaire example, shown for '"canal subgrade."'

ATTACHMENT B

Draft Roadmap

Table B1.—Prioritized draft research roadmap for canals infrastructure

	Causal analysis (canals infrastructure)				Frequency and concern				Gap analysis			Research needs		Total
#	Structure	Outcome	Process	Cause	Frq	Nrm 0-3	Conc. Data	Avg 0-3	Available tools	Gaps in existing tools	L - H 0-5	Results are high value	L - H 0-5	0-16
1	Canal subgrade	Unmitigated seepage	Piping/internal erosion	Unsuitable foundation/ embankment materials and improper compaction. Seepage through animal burrows or along deep-rooted vegetation	13	1.86	5 Maj	3.00	Remove/reconstruct/ replace, compact unsuitable materials	Need more remote monitoring of canal water levels in older systems. Need inexpensive, nondestructive means to monitor extent or progression of seepage (aerial methods, piezometers, LiDAR/photogrammetry/change software/thermal detection and moisture probes/ground-penetrating radar or transient electromagnetic (TEM) resistivity, geographic information system tools). Need seepage mitigation methods. Need effective and cost-efficient means to cut off flows through embankment. Need to understand and quantify inflow-outflows and seepage rates (Bureau of Reclamation-wide).	3.75	**Effective canal seepage detection methods or technologies for use by engineers or field staff to more clearly define seepage paths**	4.00	**12.61**
2	Canal lining	Cracked/buckled/ bulged panels no longer perform their intended function and may lead to seepage issues	Concrete liner condition changes by cracking, buckling, or bulging	Rapid drawdown rates, freeze-thaw, poor construction material or age-related degradation, unstable soils/ settlement, embankment movement	21	3.00	3 Maj; 6 Mod; 3 None	1.75	Patch with sealants, grout epoxy, or more concrete. Remove/ replace deteriorated lining. Excavate and rest panels. Technical specialist to offer construction/placement guidance.	Need to establish and implement methods/technologies to identify, monitor, and replace damaged concrete linings. Need underwater-applied crack sealant and panel repair materials and methods. Need underwater concrete placement specification. Need coffer dam style repair methods. Need improvements in flexible liner technology. Need cost-effective means to monitor/ inspect watered canal. Need best construction practices courses for the different regions.	3.50	**A) Underwater canal lining repair materials and methods for cracked, buckled, or bulged linings (underwater crack sealants, grouts, etc.)** **B) Underwater canal panel placement material or method**	3.50	**11.75**
3	Canal subgrade	Burrows and holes in embankment leads to seepage issues	Animal or rodent burrowing	Water and food available for animals or rodents to inhabit embankments	8	1.14	1 Mod; 1 None	1.00	Rodent bait stations, fill holes or burrows	Need more effective means to deter/control rodents. Need to develop effective methods to repair animal burrows effectively and in a time- and cost-efficient manner.	4.25	**A) Tools to control or prevent animal burrowing in canals (nonhazardous)** **B) Effective methods for repair of animal burrows in canals**	4.25	**10.64**
4	Canal subgrade	Vegetation removal requires service interruption and expensive re-compaction (for some canals) and leads to seepage issues	Trees/deep-rooted vegetation growth	Canal provides water for large vegetation to thrive	11	1.57	1 Maj; 1 Mod	2.50	Establish and implement a vegetation removal program. Mechanical cutting, goats, etc.	Need safe herbicides near water. Need more effective means to control vegetation.	3.00	**A) Tools to control or prevent woody vegetation in canals (nonhazardous)** **B) Tools to control or prevent waterborne vegetation in canals (algae blooms, watergrass, etc.) (nonhazardous)**	3.50	**10.57**
5	Siphons	Siphon pipe leak or failure [1]	Siphon pipe condition deteriorates or prestressing wires fail	Corrosion of prestressing wires or pipe wall. Degradation of pipe.	6	0.86	5 Maj	3.00	Repair. Remove/ replace. Eddy current inspections. Acoustic fiber optics. GIS data management.	Prestressed concrete cylinder pipe (PCCP) repair method needed. Need improved protective coating life. Need safe, inexpensive inspection methods or tools for metal pipe and concrete pipe. Need carbon fiber repair methods. Need coatings guidance as it relates to buried and exposed metal siphon pipes. This has already had a lot of attention.	2.75	Improved inspection methods to reduce siphon pipe failure rates. Less expensive repair methods to repair pipe in lieu of replacement and associated costs.	2.75	**9.36**
6.1	Canal lining	Geomembrane damaged	Mechanical damage to exposed membranes	Sediment/vegetation removal procedures, weathering, floating, animal damage	5	0.71	1 Mod	2.00	Cover membranes with soil or concrete	Need for low-cost methods to protect and/or repair exposed geomembranes. Best practices for covering membranes for site-specific conditions. Guide to repair and cover to complete construction. Simpler geomembrane repair methods that do not require specialized equipment.	3.00	**Improved, less expensive canal lining, cover, and repair materials and methods (which districts can install themselves – low tech)**	3.25	**8.96**
6.2	Gates - turnouts	Unsuitable corrugated metal pipe replaced	Corrugated metal pipe deterioration	Corrosion or mechanical damage	2	0.29	1 Mod	2.00	Remove/replace pipe	Replace corrugated metal pipe with plastic pipe with longer service life. Need for acceptable plastic pipe replacement alternatives and installation practices. Improved plastic pipe selection and installation practices.	3.33	**Resolve identified performance issues for lightweight pipe as an alternative to reinforced concrete pipe through embankments (see Federal Emergency Management report)**	3.33	**8.96**

Table B1.—Prioritized draft research roadmap for canals infrastructure

	Causal analysis (canals infrastructure)				Frequency and concern				Gap analysis			Research needs		Total
#	Structure	Outcome	Process	Cause	Frq	Nrm 0-3	Conc. Data	Avg 0-3	Available tools	Gaps in existing tools	L - H 0-5	Results are high value	L - H 0-5	0-16
7	Canal lining	Water delivery losses	Water seeps through embankment	Lack of lining	2	0.29	1 Maj	3.00	Line canal or pipe	Concrete and geomembrane linings are available. Underwater placement method may be needed. Potential for improved lining methods of in-service canals (other than geomembrane and concrete).	2.50	**Methods and materials for underwater placement of canal linings**	2.75	**8.54**
8	Siphons	Siphon pipe corrodes or fails	Interior coating deteriorates or concrete degrades	Coating degrades and corrosion is uncontrolled	6	0.86	1 Maj	3.00	Periodic inspections and coating repairs	Need new coatings and patching techniques	2.25	Protective interior linings to prevent siphon pipe corrosion and reduce failure rates	2.25	**8.36**
9	Gates - turnouts	Trash rack clogged. Water surface level gradient possible across rack.	Weeds clogging trash rack	Excess or unusual weed growth	3	0.43	1 Mod	2.00	Clean rack/remove weeds	Need weed mitigation measures	2.50	Reduced rates or clogged trash racks or improved mitigation measures against excess or unusual weed growths	2.50	**7.43**
10	Check structure	Failure of concrete/structural component	Concrete/structural components deteriorate	Corrosion, concrete deterioration, scour, erosion behind structure	11	1.57	1 Maj; 1 Mod; 2 Min	1.75	Repair or replace structure. Routine inspections.	Need state-of-the-art concrete/structural repair method. Need longer-lasting protective coatings and seals. Need more personnel to be able to review structures.	1.75	Better repair methods to maintain check structure's health, longer maintenance cycles, and more effective maintenance planning	1.75	**6.82**
11	Gates - turnouts	Turnout headgate failure and/or won't open or delivery pipe failures	Turnout headgate or delivery pipe condition deteriorates	Corrosion or degradation of turnout headgate or delivery pipe, coating deterioration	9	1.29	1 Maj	3.00	Routine inspections and maintenance	Need more video inspections of turnout delivery pipes and appurtenances	1.00	Better inspection methods and tools to reduce gate-turnout failure rates	1.50	**6.79**
12	Gates - turnouts	Sediment removal	Sediment buildup	Sediment in water	2	0.29	1 Mod	2.00	Remove sediment or incorporate passive removal, i.e., divert out of system or stilling basins	Need better sediment removal technologies or methods. Need better passive removal methods.	2.25	More efficient sedimentation removal or reduced rates of sedimentation removal maintenance. Need more information. This may be a problem from 100 years ago.	2.00	**6.54**
13	Siphons	Siphon flow rate greatly reduced or stopped	Siphon obstruction	Debris catches or deposits in siphon	3	0.43	1 Maj	3.00	Clean out as needed. Issue is site specific.	Need self-cleaning siphons	1.25	Reduced siphon obstruction rates or mitigation practices	1.25	**5.93**
14	Canal lining	Maintenance is either expensive or causes brief service interruption	Maintenance and inspections	Routine and re-occurring	1	0.14	1 Mod	2.00	Improved service life	Canal lining materials with lower life cycle costs	2.00	None apparent	1.75	**5.89**
15	Diversion dam	Failure of concrete/structural component	Concrete/structural components deteriorate	Concrete deterioration, corrosion, too short of a timeline when choosing initial construction techniques or materials	5	0.71	1 Maj; 1 Mod; 1 None	1.67	Routine inspections and preventative maintenance. Repair concrete/structure. Replace.	Need effective and cost-efficient methods to remove old coatings, particularly red lead. Need more effective, longer-lasting paints.	1.50	Better coatings to protect diversion dam structural components from corrosion	1.25	**5.13**
16	Other	System-wide technology replacements	Not budgeted?	Obsolete technology	2	0.29	1 Mod	2.00	Remove/replace. Central Arizona Project has replaced remote terminal units with programmable logic controllers. Replaced flowmeters system wide, upgraded control cables to fiber, etc.	Need efficient means to stay current with rapidly changing technologies. Need best practices for technology management. Need easier means to upgrade technology while maintaining necessary security.	1.50	More consistency in use of technology and applications of best-available technology across Reclamation.	1.25	**5.04**
17	Canal subgrade	Flood breech	Surplus of water not controlled	Cross drainage flood appurtenances did not function properly, washout, overtopping	4	0.57	1 Maj	3.00	Cross drainage maintenance	Cross drainage maintenance ensures proper functionality	0.75	Low priority maintenance that is often neglected	0.50	**4.82**

Table B1.—Prioritized draft research roadmap for canals infrastructure

	Causal analysis (canals infrastructure)				Frequency and concern				Gap analysis			Research needs		Total
#	Structure	Outcome	Process	Cause	Frq	Nrm 0-3	Conc. Data	Avg 0-3	Available tools	Gaps in existing tools	L - H 0-5	Results are high value	L - H 0-5	0-16
18	Siphons	Trash rack corroded or filled with debris	Debris buildup	Equipment is not effective or trash rack corrodes	2	0.29	1 Mod; 1 None	1.00	Establish a program for recoating the structural steel members and consider cathodic protection installation. Clean, adjust, or work with manufacturer to improve rake performance.	Need safe tools to remove debris from trash racks. Need trash rakes that will work.	1.75	More effective trash rake/rack combination. This may be an old problem that has already been solved.	1.75	**4.79**
19	Check structure	Maintenance, failure, reduced service life or replacement	Replacement of check structures is not budgeted. Maintenance issues.	Aging and obsolete technology	4	0.57	1 Mod	2.00	Need for low-cost modular check structures that can be easily installed into existing canals	Need for low-cost modular check structures that can be easily installed into existing canals	1.00	Identification of replacement technologies or technologies, which are compatible with existing structures	1.00	**4.57**
20	Other	Failure of other feature	Replacement is low priority and not budgeted. Aging or inappropriate materials used.	Poor durability/design, age-related deterioration or other	4	0.57	1 Maj; 2 Mod	2.33	Routine maintenance and inspections. Repair. Remove/replace.	Need maintenance tracking software for operating entities to use while also making sure that it could provide a historical record for maintenance activities. Need data/technology sharing among different entities.	0.75	Improved maintenance tracking and research of future research needs	0.75	**4.40**
21	Check structure	Gate failure or replacement	Preventative maintenance on gate hoists and inspections	Corrosion due to coating deterioration or equipment failure	9	1.29	2 Mod; 2 None	1.00	Routine exercising, inspections, and preventative maintenance. Replacement. Anode installation.	Need to develop improved inspection techniques and a program to assess the condition of radial gates. Need longer-life coating technologies to reduce corrosion and maintenance costs. Related - need increased accuracy for flow measurement through radial gates.	1.00	Better inspections and reduced check structure failures rates	1.00	**4.29**
22	Diversion dam	Flood breech	Surplus of water not controlled	Old push-up dams breech in floods, lack of cutoffs	2	0.29	2 Maj	3.00	Replacement of old diversion dams. Very site-specific concern; not widespread.	Technology exists, but funding is low priority	0.25	Better understand flood risks and probabilities	0.50	**4.04**
23	Check structure	Not known	Not known	Lack of check structures	1	0.14	1 Mod	2.00	Add checks as needed	Need for low-cost modular check structures that can be easily installed into existing canals	0.75	Materials with improved durability and lower life cycle costs	0.75	**3.64**
24	Gates - turnouts	Maintenance is either expensive or causes brief service interruption	Maintenance and inspections	Replacement of gates and turnouts is not budgeted. Site-specific issues.	2	0.29	2 Mod	2.00	Replace as needed	Need for low-cost modular gates that can be easily retrofitted or replaced into existing canals	0.75	None apparent	0.50	**3.54**
25	Other	Culvert not functioning properly	Deteriorated or undersized culvert pipe	Deterioration, underdesigned culvert, or change in system volumes	2	0.29	1 Mod	2.00	Remove/replace culverts. Clean out culverts. Video inspect culverts.	Scheduling and documentation for maintenance (cleaning) of inverts. Existing tools are sufficient.	0.50	Low priority maintenance that is often neglected	0.25	**3.04**
26	Diversion dam	Maintenance is either expensive or causes brief service interruption	Maintenance and inspections	Sedimentation adds to maintenance costs. Added costs due to lack of maintenance.	7	1.00	1 Mod; 1 Min; 1 None	1.00	Repair/replace equipment. Blast and recoat. Concrete repair. Anode replacement.	Need simpler equipment that requires little maintenance. Maintenance issues should be referred to FAC Operations and Maintenance Team?	0.50	Less or less expensive maintenance	0.50	**3.00**

[1] Moratorium on PCCP – may become legislated research with other funding sources.