

RECLAMATION

Managing Water in the West

Environmental Issues for Water Delivery and Management Research Roadmap - DRAFT

**Research and Development Office
Science and Technology Program**



**U.S. Department of the Interior
Bureau of Reclamation**

April 2018

Cover Image: One example of ecosystem services could be related to valuing benefits gained from restoration projects implemented for habitat improvements, such as this side channel in the Methow River (WA) where engineered log jams were constructed to increase perennial side channel flow and juvenile salmon habitat. November 2, 2012 photograph courtesy of Dave Walsh, Reclamation.

RECLAMATION

Managing Water in the West

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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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**Environmental Issues for Water Delivery and
Management Research Roadmap**

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Executive Summary

A research roadmap has been prepared for topics that fall within the Reclamation Science and Technology (S&T) Program research area “Environmental Issues for Water Delivery and Management” (EN). The roadmap was developed based on input from two collaborative workshops with Reclamation and United States Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC), a multi-agency workshop on prize competitions, and input from over 50 technical specialists and resource managers at Reclamation. The EN area is broad, so topic level research needs are presented in five research categories:

1. Water Delivery Reliability (EN-1)
2. Invasive Species (EN-2)
3. Water Quality (EN-3)
4. Sediment Management (EN-4)
5. River Habitat Restoration (EN-5)

Cross-cutting themes were identified that highlight needs in inter- and intra-agency collaboration, best practices and transfer of lessons learned in ecosystem services and adaptive management, and better tools for reducing uncertainty and increasing linkages among disciplines. Priority research topics listed below were identified for each of the five categories to help facilitate collaborations and focus research proposals during the S&T Program’s annual call for proposals on the most urgent research needs.

Water Delivery Reliability (EN1) Priorities

- Determine water operations impacts to flow hydrographs and water dependent ecological resiliencies
- Quantify ecosystem services related to environmental flows
- Develop best practices to implement adaptive management for operations to support environmental restoration
- Operation strategies to reduce stranding of aquatic organisms during low and high flows

Invasive Species (EN2) Priorities

- Determine effective site-specific uses of existing and innovative integrated pest management (IPM) for riparian and aquatic vegetation that reduces flow conveyance or impedes operations (e.g., Phragmites, Eurasian watermilfoil)
- Determine effective site-specific uses of existing and innovative integrated pest management (IPM) for mussels, fish, birds, mammals, etc. that affect threatened or endangered species or impede operations

- Improve detection, spread prevention, and monitoring methods in order to identify invasive species infestations and reduce range expansion
- Determine impacts of invasive species and mitigation measures to protect site-specific threatened or endangered species, infrastructure, or operations

Water Quality (EN3) Priorities

- Improve understanding of operational effects on salinity, temperature, oxygen, turbidity and nutrient levels in flow releases, and in-reservoir processes
- Predict, manage, and monitor effects of hydrologic variability on water quality

Sediment Management (EN4) Priorities

- Develop indirect methods to estimate reservoir sedimentation
- Improve understanding and practices of how sediment transport and sediment augmentation interacts with channel morphology to create topographic complexity important for downstream habitat
- Improve monitoring methods to track sediment released from reservoirs and associated impacts
- Develop guidelines for managing sediment transport and deposition associated with dam removal or reservoir sluicing

River Habitat Restoration (EN5) Priorities

- Develop alternatives that eliminate need for fish screens
- Develop ecosystem health indicators throughout watershed
- Better understand effects of ecohydraulics on habitat availability, connectivity and food webs for aquatic species
- Improve upstream and downstream fish passage at dams
- Evaluate post-construction habitat and design feature performance for rehabilitation projects
- Improve future channel change predictions in habitat rehabilitation areas and near Reclamation infrastructure

Next steps for roadmapping in Environmental Issues for Water Delivery and Management include outlining a few of the cross-cutting themes or areas of priority research needs in more detail. The objective is to increase information sharing within Reclamation and explore more collaboration and partnership opportunities to accomplish future research. Possible focus areas include:

- River restoration implementation and design successes and challenges

- Numerical model tools for solving environmental management issues
- Characterizing ecosystem services of environmental projects

1.0 Introduction

The Bureau of Reclamation (Reclamation), established in 1902, is currently the largest wholesale water supplier in the United States. Reclamation operates 348 reservoirs with a total storage capacity of 245 million acre-feet of water in the 17 western states. Water supplied from Reclamation reservoirs is used to irrigate 10 million acres of farmland which produce 60-percent of the Nation's vegetable and one-quarter of its fresh fruit and nut crops. Reclamation also delivers 10 trillion gallons of water to more than 31 million people each year. Reclamation is also the second largest producer of hydropower in the United States where the 58 hydroelectric power plants have annually produced, on average over the last 10 years, 44 billion kilowatt-hours. Reclamation manages 308 recreation sites that have 90 million visits annually. In addition to accomplishing water delivery, Reclamation's mission includes operating water facilities in both an environmentally and economically sound manner.

To help address environmental issues, the Reclamation Science and Technology (S&T) Program facilitates research in an area entitled "Environmental Issues for Water Delivery and Management" (EN), also referred to as eco-hydraulics, in collaborative research discussions with the U.S. Army Corps of Engineers (USACE) (Reclamation, 2017).

Environmental Issues for Water Delivery and Management (EN) - Improve the reliability of Reclamation water deliveries by producing effective solutions, tools, and practices that Reclamation water managers can use to address state and federal environmental compliance and court orders.

Research addressing environmental issues prevents or reduces the risk of Reclamation projects not fulfilling trust responsibilities or violating environmental requirements defined by Federal and State laws, resulting in water or power deliveries being interrupted, reduced, or eliminated. Specifically, research in the environmental area aims to accomplish the following objectives:

- Increasing reliability and sustainability of water delivery.
- Increasing infrastructure sustainability.
- Reducing impacts to environmental, fish, wildlife and recreation use.
- Reducing maintenance, inspections, and repair times needed for a facility.
- Reducing costs compared to current business practices.
- Meeting environmental compliance requirements.

Research is accomplished within Reclamation by subject matter experts, collaborations with outside partners, and more recently through prize competitions. Common themes in EN research between 2004 and 2016 are characterized by a "word cloud" that highlights the most frequently

occurring words in bigger text, based on research titles (Figure 1). Water, not surprisingly, is the central theme followed by rivers that are relied upon to supply the water, and aquatic species (most commonly fish) using the river corridors through which water is conveyed. The word cloud also emphasizes an increase in research related to management of invasive species, which require unique management needs at many Reclamation facilities.



Figure 1. Common terms in recent EN research project titles.

This report provides an EN research roadmap intended to serve as a multi-year outlook of research needs applicable to addressing environmental issues in Reclamation (see Section 2 for roadmap development). The EN research area is broad, including a wide range of environmental issues facing Reclamation projects. During roadmap development, several cross-cutting themes and priority research needs were identified that are highlighted in Section 3. To organize topic level research needs, the EN roadmap is broken into five research categories:

1. Water Delivery Reliability (EN-1)
2. Invasive Species (EN-2)
3. Water Quality (EN-3)
4. Sediment Management (EN-4)
5. River Habitat Restoration (EN-5)

For each of the five categories in EN, a more complete list of research topics are provided along with a table that notes research needs and known resources. The roadmap provides current thinking on research needs within Reclamation, but should not preclude emerging management

or resource issues that arise outside of this roadmap. Rather the roadmap should be considered a living document that can be updated to include additional innovations and ideas as they arise.

Coordinators are listed for each category that can assist researchers or resource managers facilitate partnerships and provide additional information regarding research ideas. Researchers are encouraged to use the roadmap to learn about agency research needs related to environmental issues, and gain ideas on collaborations with partners and from past research listed for given topics. Reclamation resource managers are encouraged to use the roadmap to identify opportunities for collaboration for issues of interest to enhance technology transfer and increase opportunities for increased expertise within Reclamation. Research coordinators are encouraged to use the roadmap to identify opportunities to assist with topics not being addressed by traditional research where more refined roadmaps or prize competitions may be needed.

2.0 Roadmap Development

The EN research roadmap was collaboratively developed through input from Reclamation subject matter experts and resource program managers, along with input from USACE. The following list describes the steps implemented to develop the EN research roadmap.

1. Idea generation through collaborative discussions (pre- 2016)
 - a. Workshop with USACE held May 17-19, 2011 in Sacramento, CA to identify research needs common to both federal agencies
 - b. Workshop on “Bureau of Reclamation River Restoration Programs: A Summary of 16 Programs and Shared Institutional Challenges”, September 14 & 15, 2011, Albuquerque, New Mexico, hosted by the Bureau of Reclamation and the Utton Center at the University of New Mexico School of Law
 - c. Annual meetings since 2015 with Reclamation and USACE ERDC to identify collaboration opportunities in eco-hydraulics
 - d. Prize competition workshop in fall 2014
2. Roadmap team formed to prepare a roadmap report (September 2016)
 - a. Subject matter experts from water, environmental and ecosystems division in Technical Service Center (TSC), subject matter expert from Mid-Pacific (MP) Region, environmental research coordinator from S&T, representative from environmental compliance division in Policy and Administration Office (PAO)
3. Five categories identified to break out research topics within EN (October 2016)
4. Research needs survey (December 2016)
 - a. Target audience: Reclamation subject matter experts (all regions, TSC, PAO)
 - b. Survey outcome: generated list of EN research needs
5. Prioritization survey (March 2017 – See Appendix B)

- a. Target audience: Reclamation technical staff, program managers, and policy and administration office (49 participants representing all five regions, PAO, and TSC)
 - b. Survey outcome: priority EN topics identified based on input from survey; 5 new research topics added;
 - c. Ten survey topics not reported because the topic fell in another research area (e.g. infrastructure needs) or post-survey evaluation with technical experts noted existing resources already available
6. Prepare roadmap report (September 2017)
 - a. Smaller team synthesizes research survey topics and accomplishes literature review to document current resources and research needed for each research topic
 - b. For reporting purposes, the original survey topics were separated into either a broader research topic or more detailed science needs to accomplish a given topic. In some cases survey topics were combined where concepts were similar.
7. Team review of roadmap report (October-November 2017)
8. Technical peer review and research office review of roadmap report (November 2017 - January 2018)
9. External review by ESA team (February 2018)

3.0 Priority Environmental Research Needs

Priority EN topics relate to urgent challenges facing Reclamation programs and operators when addressing environmental issues for water delivery and management. Priority topics received the most survey votes (top 20 %) or were important to all five Reclamation regions.

Water Delivery Reliability (EN1) Priorities

- Determine water operations impacts to flow hydrographs and water dependent ecological resiliencies (e.g. ecosystems, groundwater recharge, biodiversity)
- Quantify ecosystem services related to environmental flows
- Develop best practices to implement adaptive management for operations to support environmental restoration
- Operation strategies to reduce stranding of aquatic organisms during low and high flows

Invasive Species (EN2) Priorities

- Determine effective site-specific uses of existing and innovative integrated pest management (IPM) for riparian and aquatic vegetation that reduces flow conveyance or impedes operations (e.g., Phragmites, Eurasian watermilfoil)
- Determine effective site-specific uses of existing and innovative integrated pest management (IPM) for mussels, fish, birds, mammals, etc. that affect threatened or endangered species or impede operations
- Improve detection, spread prevention, and monitoring methods in order to identify invasive species infestations and reduce range expansion
- Determine impacts of invasive species and mitigation measures to protect site-specific threatened or endangered species, infrastructure, or operations

Water Quality (EN3) Priorities

- Improve understanding of operational effects on salinity, temperature, oxygen, turbidity and nutrient levels in flow releases, and in-reservoir processes
- Develop methods to predict, manage, and monitor effects of hydrologic variability on water quality (e.g. future hydrologic regimes, sea level fluctuations in estuarine environments)

Sediment Management (EN4) Priorities

- Develop indirect methods to estimate reservoir sedimentation
- Improve understanding and practices of how sediment transport and sediment augmentation interacts with channel morphology to create topographic complexity important for downstream habitat
- Improve monitoring methods to track sediment released from reservoirs and associated impacts
- Develop guidelines for managing sediment transport and deposition associated with dam removal or reservoir sluicing

River Habitat Restoration (*EN5) Priorities*

- Develop alternatives that eliminate need for fish screens
- Develop ecosystem health indicators throughout watershed

- Better understand effects of ecohydraulics on habitat availability, connectivity and food webs for aquatic species
- Improve upstream and downstream fish passage at dams
- Evaluate post-construction habitat and design feature performance for rehabilitation projects
- Improve future channel change predictions in habitat rehabilitation areas and near Reclamation infrastructure

Cross-cutting Themes

During roadmap surveys, several cross-cutting themes occurred that apply to all of the EN categories. These themes, noted below, provide opportunities for broader research needs that may be addressed in research proposals, or through the development of agency teams and collaborative meetings.



Communication

- Promote *intra and inter-agency collaboration* teams and networking related to environmental issues (Figure 2)

Figure 2. Example of inter-agency collaboration during workshop with Reclamation and USACE to identify research needs and facilitate partnerships.

Operations and Design

- Increase operational flexibility by identifying best practices and lessons learned in *adaptive management* for improved understanding and application across Reclamation (see Williams et al., 2009 and Williams et al., 2012)
- Develop best practices and lessons learned in *river restoration* for improved understanding and implementation across Reclamation
- Develop *engineering criteria and best practices* for stream restoration
- Promote *water management sustainability* by developing methods that balance operational needs to comply with ESA requirements in the near-term (present to a

few years) while allowing for longer-term study and monitoring inherent in adaptive management learning

Ecosystem Services

- Develop guidance in *ecosystem services* for improved understanding and application across Reclamation

Modeling

- Generate modeling tools that *improve performance and reduce uncertainty* for Reclamation projects
- Explore modeling tools that effectively *link predictions among multi-disciplines*, such as hydrology, hydraulics, groundwater, sediment erosion and deposition, stream temperature, water quality, vegetation growth and mortality, aquatic and terrestrial habitat, species competition, and species populations (Figure 3)
- Prepare a *Reclamation model roadmap(s)* to identify current tools available for answering management questions related to environmental issues and what future research is needed to improve model capabilities; model roadmap development would also facilitate outreach and collaboration among Reclamation technical staff with program office needs

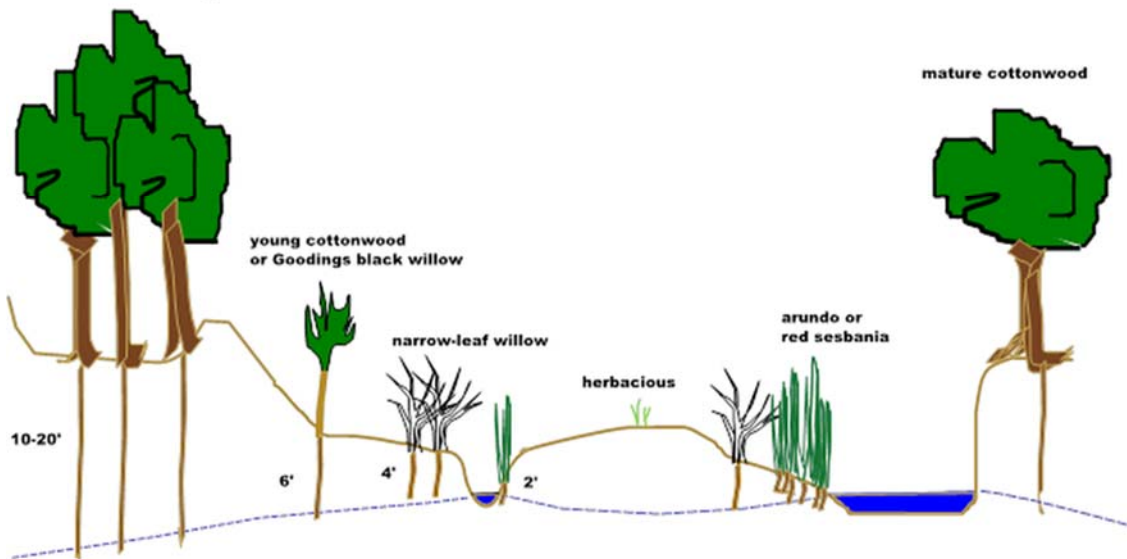
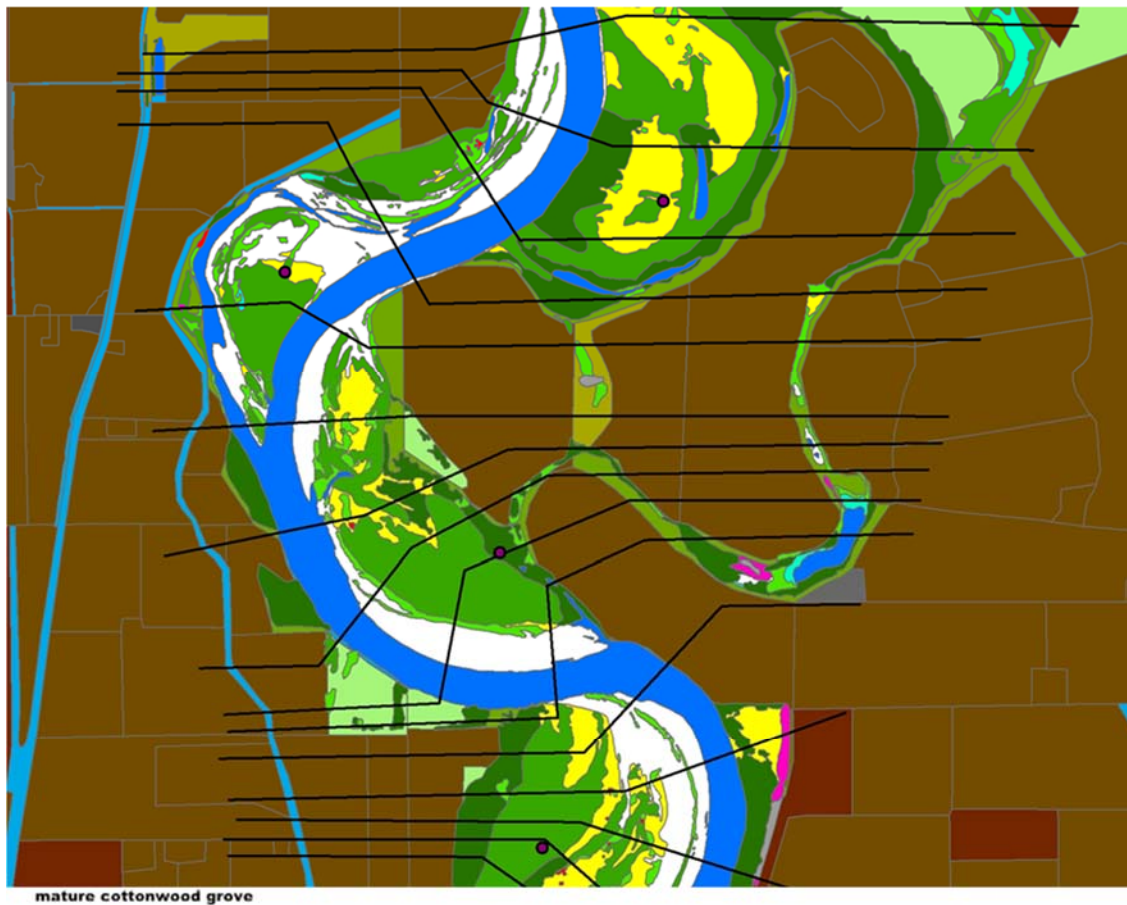


Figure 3. One area of model research involves linking reservoir flow releases to downstream riparian vegetation growth and mortality (modified from Fotherby, 2012).

4.0 Prize Competitions – Environmental Compliance Theme Area

Prize competitions are a unique tool for accelerating research to address elusive mission and operations challenges through private sector and “citizen solvers”. By tapping into a wealth of knowledge through on-line crowd-sourcing techniques, prize competitions help Federal agencies to advance research and development and drive innovation. Prize competitions are best suited to advance tough problems where solutions have been elusive, to provide new ideas when research becomes stuck, or to move along problems where market forces may not provide sufficient incentives to solve or solve well. Conversely, traditional research can help achieve “reduction-to-practice” of ideas and concepts obtained through prize competitions through follow-up traditional research and in-house demonstration projects, CRADAs, and additional competition stages in which theoretical concepts are proven in the laboratory or in the field. The diagram below depicts the relationship between competitions and other forms of research and development (Figure 4).

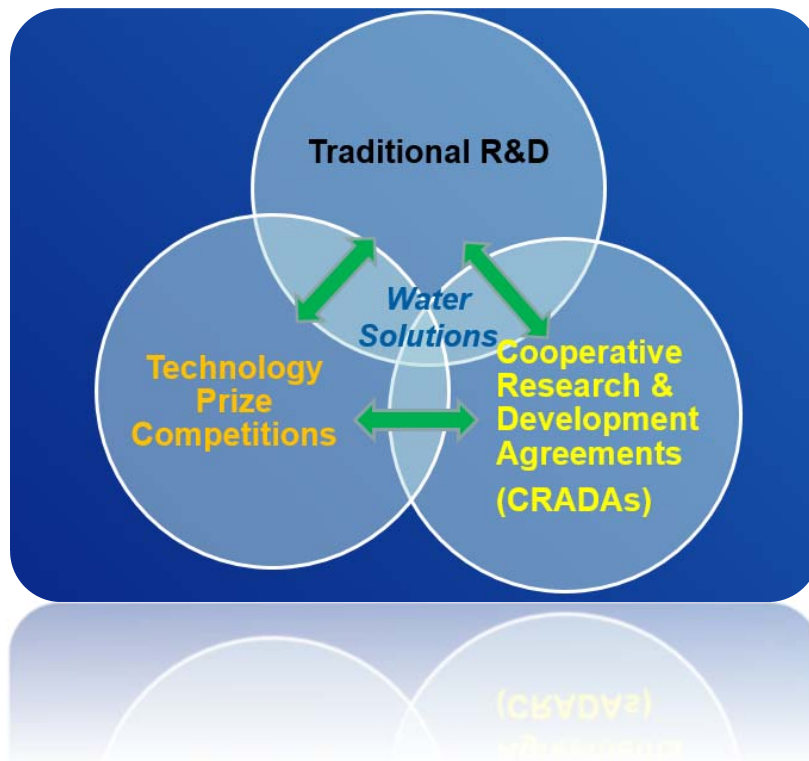


Figure 4. Illustration of how prize challenges fit into agency research options.

Reclamation categorizes its prize competitions research needs into three main theme areas:

- Water Availability

- Infrastructure Sustainability
- Environmental Compliance

Prize competition topics are identified through a collaborative process. Between 2014 and 2015, Reclamation conducted multi-agency workshops with principal researchers, facility staff and managers and other stakeholders to identify high-priority research topics in each of the three theme areas that may be appropriate for a prize competition. As resources allow, Reclamation is launching competitions in these high-priority areas and updating its prize competition topics as priorities change.

There are numerous prize competitions that support the Environmental Compliance Priority Research Needs discussed in Section 3. The below table demonstrates the relationship between completed, underway or planned competitions and the EN research areas and needs they support (Table 1). Additionally, the tables in Appendix A further identify where a correlation between specific EN research topics and prize competitions exists (indicated by an asterisk *) and describe promising research ideas that have resulted from the prize competitions under “Science Need” for a specific topic, as applicable.

Table 1. List of prize competitions and correlating EN research topics.

| Prize Competition | EN Research Category | EN Research Topic | Prize Status |
|--|---------------------------------|--|---|
| New Concepts for Remote Fish Detection | River Habitat Restoration (EN5) | Improve detection and tracking of movement and migration of individuals and/or species | Complete 10/2015 6 winning solutions |
| Quantifying Drift Invertebrates in River and Estuary Systems | River Habitat Restoration (EN5) | Better understand effects of ecohydraulics on habitat availability and food webs for aquatic species | Complete 1/2016 5 winning solutions |
| Downstream Fish Passage at Tall Dams | River Habitat Restoration (EN5) | Improve upstream and downstream fish passage at dams | Complete 7/2016 4 winning solutions |
| Indirect Estimates of Reservoir Water Storage | Sediment Management (EN4) | Develop indirect methods to estimate reservoir sedimentation | Complete 7/17 1 winning solution |
| Eradicating Invasive Mussels in Open Water Stage 1, 2 and 3 | Invasive Species (EN2) | Determine effective site-specific uses of existing and innovative integrated pest management (IPM) for mussels, fish, birds, mammals, etc. that affect | Launched 12/18 |

| | | | |
|---|---|--|----------------------------|
| | | threatened or endangered species or impede operations | |
| Improving removal and management of reservoir sediment | Sediment Management (EN4) | Improve effectiveness of reservoir sediment dredging/management technologies to improve sustainability | Target Launch Fall 2018 |
| Improving ability to control water temperatures of reservoir release flows | Water Delivery Reliability (EN1) Water Quality (EN3) | Modify reservoir operations to better manage temperatures for downstream fisheries Improve methods for water temperature control downstream of dams | Target Launch Winter 2019 |
| Eradicating non-native fish species | River Habitat Restoration (EN5) | Enhance strategies to reduce piscivorous (feeding on fish) predation by non-native species | Planned Future Competition |
| Reducing loss of threatened and endangered fish due to fish predation | River Habitat Restoration (EN5) | Enhance strategies to reduce piscivorous (feeding on fish) predation by non-native species | Planned Future Competition |
| Improving upstream fish passage at tall dams | River Habitat Restoration (EN5) | Improve upstream and downstream fish passage at dams | Planned Future Competition |
| Developing innovative fish screening/exclusion techniques | River Habitat Restoration (EN5) | Develop alternatives that eliminate need for fish screens | Planned Future Competition |
| Reducing entrainment of larval fish at screens and intakes (EN5 Topic Number 1, future) | River Habitat Restoration (EN5) | Improve fish screen functionality and efficiency | Planned Future Competition |

More information on past, present, and future prize competitions can be found on Reclamation's Water Prize Competition Center (www.usbr.gov/research/challenges/) as well as posted on the

Federal Government's prize competition platform www.challenge.gov. Background information about Reclamation's prize competition program can be found in the Research and Development (R&D) Office's Winter 2015-2016 "The Knowledge Stream: Water Technology Prize Competitions Issue" (<https://www.usbr.gov/research/docs/ks/ks-2016-01.pdf>).

Coordination Contact: Kerry Whitford, kwhitford@usbr.gov, 303-445-2949, S&T Prize Competitions Administrator, Science and Technology Office, Bureau of Reclamation, Denver, CO

5.0 Water Delivery Reliability (EN1)

Description: Improve the reliability of Reclamation water supplies by finding innovative means to address aquatic and terrestrial ecosystem and species needs while still meeting water delivery contracts (Figure 5).

Coordination Contact: Connie Svoboda, csvoboda@usbr.gov, 303-445-2152, Hydraulic Investigations & Laboratory Services, Technical Service Center, Bureau of Reclamation, Denver, CO

Number of Funded Projects: 12 research projects funded between 2013 to 2017 (research also occurs in Water Operations and Planning area)

R&D Office Knowledge Stream: None identified

Agency Working Teams and Workshops:

SECURE Reservoir Operations Team: focus on developing Reclamation guidance to identify current agency practices to consider the best available scientific information, enhance existing operational flexibility for multiple benefits, and planning for future operations. Reservoir Operations Pilot workshop held 10/24-26/2017 in Denver. Reclamation Contact: Avra Morgan, aomorgan@usbr.gov, 720-544-4207

Research Topic List :

This list includes a summary list of research topics described resulting from the surveys described in Section 2.2. The original survey topics were synthesized to organize the ideas into topics or science needs associated with the topics (See Table 2 in Appendix A for more detail on science needs and resources for each topic in the list below). The highest priority topics identified by top 20% of votes or noted as important to all regions are highlighted in the list below in bold.

1. Develop Reclamation-wide database of irrigation, municipal and industrial, and environmental flow deliveries
2. Increase tools available to meet water needs for environmental flows (e.g. wetlands, riparian zone, aquatic invertebrates, fish, and wildlife)
3. Use flushing flows for habitat maintenance with recreational uses
4. Modify reservoir operations to better manage temperatures for downstream fisheries
5. **Determine water operations impacts to flow hydrographs and water dependent ecological resiliencies (Figure 6) (PRIORITY)**
6. Develop methods for environmental flow operations to respond to hydrologic variability
7. **Quantify ecosystem services related to environmental flows (PRIORITY)**

8. Improve watershed management to control erosion and flooding
9. **Develop best practices to implement adaptive management for operations to support environmental restoration (PRIORITY)**
10. **Operation strategies to reduce stranding of aquatic organisms during low and high flows (PRIORITY)**



Figure 5. Canyon Ferry Dam on Upper Missouri River (left) operated by Reclamation and Helena Valley Irrigation (right) that uses water supplied from Canyon Ferry. Photographs courtesy of Marketa McGuire, Reclamation.



Figure 6. Example wetland where research on effect of reservoir releases to downstream ecosystem could benefit management strategies. Photograph courtesy of Scott O'Meara, Reclamation.

6.0 Invasive Species (EN2)

Description: Develop and improve techniques for detecting and managing aquatic and riparian invasive species that consume Reclamation water supplies or impede Reclamation water deliveries, or harm threatened or endangered species. (Figure 7 and Figure 8). Example invasive species include plankton, mollusks, insects, vegetation, reptiles, amphibians, fish, birds, mammals, etc. that affect native, threatened, and endangered species or impede operations (Figure 9).

Coordination Contact: Sherri Pucherelli, spucherelli@usbr.gov, 303-445-2015, Hydraulic Investigations & Lab Services Group, Technical Service Center, Bureau of Reclamation, Denver, CO

Number of Funded Projects: 46 research projects funded between 2013 to 2017

R&D Office Knowledge Stream: Fall 2015 “The Knowledge Stream: Invasive Mussels Issue” (<https://www.usbr.gov/research/docs/ks/ks-2015-04.pdf>); invasive species issue planned for FY2018

Agency Working Teams and Workshops:

- National Invasive Species Council
- DOI Invasive Species Coordinator Team
- Reclamation Invasive Species Coordinator Team
- Reclamation Quagga Mussel Task Force
- Government Environmental DNA Work Group
- Numerous stakeholder task groups (contact Reclamation Detection Laboratory for Exotic Species)

Research Topic List:

This list includes a summary list of research topics described resulting from the surveys described in Section 2.2. For invasive species, survey results were merged into four high priority topics identified by top 20% of votes or noted as important to all regions. The original survey topics were synthesized to organize the ideas into topics or science needs associated with the topics (See Table 2 in Appendix A for more detail on science needs and resources for each topic in the list below).

1. **Determine effective site-specific uses of existing and innovative integrated pest management (IPM) for riparian and aquatic vegetation that reduces flow conveyance or impedes operations (e.g., Phragmites, Eurasian watermilfoil).**

- 2. Determine effective site-specific uses of existing and innovative integrated pest management (IPM) for mussels, fish, birds, mammals, etc. that affect threatened or endangered species or impede operations.**
- 3. Improve detection, spread prevention, and monitoring methods in order to identify invasive species infestations and reduce range expansion.**
- 4. Determine impacts of invasive species and mitigation measures to protect site-specific threatened or endangered species, infrastructure, or operations.**



Figure 7. Invasive Salvinia growing in canal affecting water conveyance. Photography courtesy Denise Hosler, Reclamation.



Figure 8. Invasive Hydrilla growing near boat ramp affecting recreation access. Photograph courtesy Denise Hosler, Reclamation.



Figure 9. Invasive Quagga mussels on bulkhead gate. Photograph courtesy Denise Hosler, Reclamation.

7.0 Water Quality (EN3)

Description: Develop and advance tools and practices that Reclamation has the mission responsibility and authority to use in managing water quality issues that are (1) linked to reclamation operations and (2) could impact the reliability of Reclamation water deliveries if not addressed.

Coordination Contact: Mike Horn, mhorn@usbr.gov, 303-445-2203, Fisheries and Wildlife Resources Group, Technical Service Center, Bureau of Reclamation, Denver, CO

Number of Funded Projects: 14 research projects funded between 2013 to 2017

R&D Office Knowledge Stream: None identified

Agency Working Teams and Workshops: None identified

Research Topic List:

This list includes a summary list of research topics described resulting from the surveys described in Section 2.2. The original survey topics were synthesized to organize the ideas into topics or science needs associated with the topics (See Table 2 in Appendix A for more detail on science needs and resources for each topic in the list below). The highest priority topics identified by top 20% of votes or noted as important to all regions are highlighted in the list below in bold.

1. Develop database for water quality parameters at Reclamation facilities
2. Improve methods for water temperature control downstream of dams
3. **Improve understanding of operational effects on salinity, temperature, oxygen, turbidity, and nutrient levels in flow releases and in-reservoir processes (PRIORITY)**
4. Improve understanding of operational effects on the transport and level of contaminants and toxic materials (Figure 10)
5. Reduce gas supersaturation downstream of dams
6. Improve understanding in trade-offs in temperature management for threatened and endangered species (Figure 11)
7. **Develop methods to predict, manage, and monitor effects of hydrologic variability on water quality (PRIORITY)**
8. Improve treatment wetlands or other vegetative remediation technologies to preserve or improve water quality (Figure 12)
9. Develop land use practices to improve water quality
10. Incorporate wildfire risks into water quality assessments
11. Quantify ecosystem services related to water quality improvements

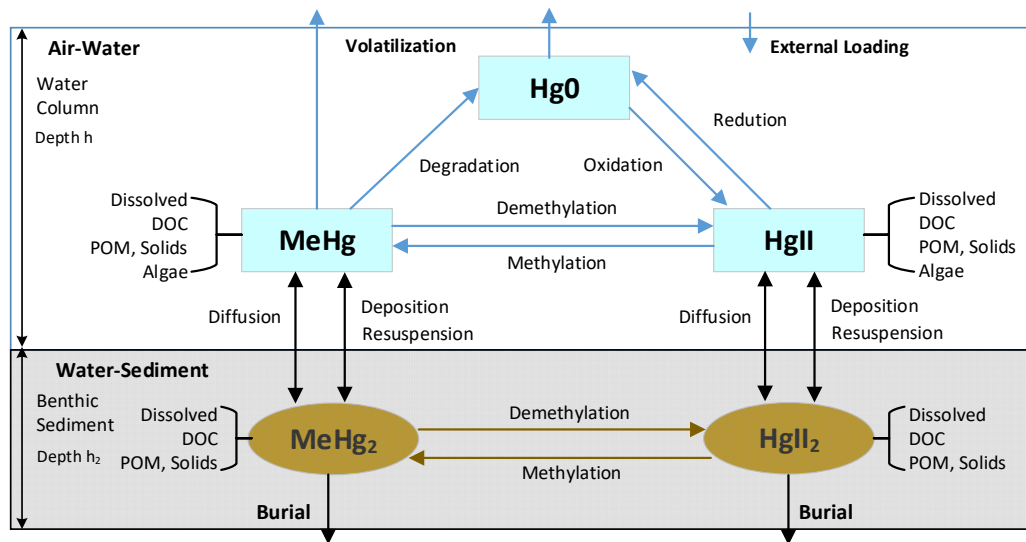


Figure 10. Example of research model linkages for improving understanding of mercury mobilization and transport in reservoirs. Image provided by Yong Lai, Reclamation.

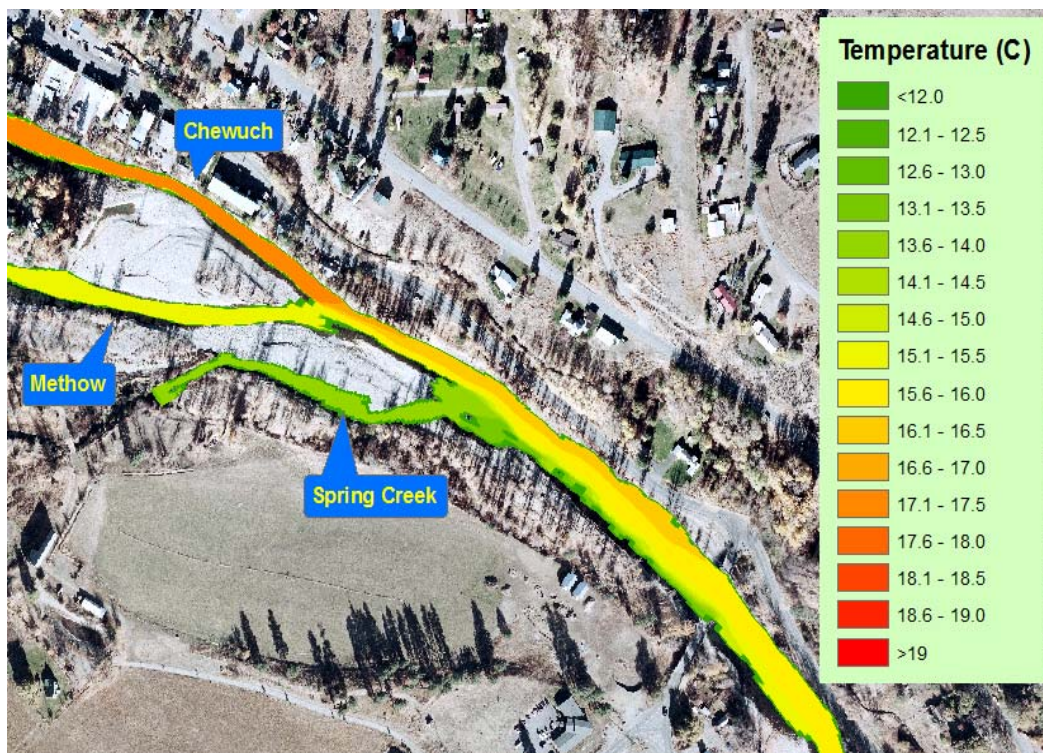


Figure 11. Research on numerical simulation of water temperature (SRH-2D) to evaluate a combination of point-source (mainstem and tributary) and non-point source (local spring) effects in reach critical for threatened and endangered species habitat. Color scale is mapped to predicted depth-averaged temperature. Image courtesy of Victor Huang, Reclamation.



Figure 12. Example of wetland on San Diego River near the Mission Park Dam where research is needed to understand impact of dam operations on flow releases and sedimentation effects. Photograph courtesy of Denise Hosler.

8.0 Sediment Management (EN4)

Description: Develop and improve sediment management solutions and tools that improve the reliability and sustainability of water deliveries from Reclamation reservoirs and associated river systems, and improve habitat conditions for threatened and endangered species.

Coordination Contact: Sean Kimbrel, skimbrel@usbr.gov, Umatilla Field Office, Bureau of Reclamation, Hermiston, OR

Number of Funded Projects: 38 research projects funded between 2013 to 2017

R&D Office Knowledge Stream: Spring 2016 “The Knowledge Stream: Reservoir Sedimentation and Sustainability” (<https://www.usbr.gov/research/docs/ks/ks-2016-02.pdf>).

Agency Working Teams and Workshops:

Reservoir Sustainability Workshop (2012; Denver, CO): Attendees included reservoir sedimentation subject matter experts from state and federal agencies, universities, and the private sector (<https://acwi.gov/sos/pubs/3rdJFIC/Contents/7C-Randle.pdf>)

National Reservoir Sedimentation and Sustainability Team: Federal agencies, universities and consultants work to create awareness on reservoir sedimentation and work toward reservoirs sustainability options (see Frequently Asked Questions about Reservoir Sedimentation and Sustainability at <https://acwi.gov/sos/>). Team is sponsored by Subcommittee on Sedimentation.

Federal Interagency Sedimentation Project: Reclamation participates in this inter-agency team whose goal is to unify and standardize research and development activities of Federal agencies involved in fluvial sediment studies (see <https://water.usgs.gov/fisp/>).

Research Topic List (highest priority in bold):

This list includes a summary list of research topics described resulting from the surveys described in Section 2.2. The original survey topics were synthesized to organize the ideas into topics or science needs associated with the topics (See Table 2 in Appendix A for more detail on science needs and resources for each topic in the list below). The highest priority topics identified by top 20% of votes or noted as important to all regions are highlighted in the list below in bold.

1. Estimate future reservoir sedimentation (volume and spatial distribution) to account for storage capacity loss over time.
2. Develop reservoir sedimentation database to track capacity loss and trigger maintenance needs
3. **Develop indirect methods to estimate reservoir sedimentation (PRIORITY)**

4. Improve understanding and guidance of reservoir operation effects on upstream channel response, including water table changes
5. Improve reservoir surveying technology and uncertainty quantification
- 6. Improve understanding and practices of how sediment transport and sediment augmentation interacts with channel morphology to create topographic complexity important for downstream habitat (Figure 13) (PRIORITY)**
7. Improve effectiveness of reservoir sediment dredging/management technologies to improve sustainability (Figure 14)
8. Develop economics of sustainable reservoir sediment management
9. Improve estimates of sediment contributions from tributaries, especially from ephemeral systems (Figure 15)
10. Enhance prediction tools to better manage sedimentation (flush fines, build sediment bars, gravel augmentation)
- 11. Improve monitoring methods to track sediment released from reservoirs and associated impacts (PRIORITY)**
12. Quantify ecosystem services related to sediment management actions
- 13. Develop guidelines for managing sediment transport and deposition associated with dam removal or sediment sluicing (PRIORITY)**
14. Improve methods to reduce sediment from water supply intakes, screens, and diversions
15. Improve methods to control wetland inflow-sediment management
16. Improve design and modeling techniques for side channel reconnection and determining sediment impacts
17. Restore estuaries and floodplains that have been heavily manipulated by dikes/levees or other human actions



Figure 13. Research is needed to understand timing and ecological benefits of gravel augmentation downstream of Reclamation facilities that have reduced natural sediment loads, especially coarse sediment. Gravel is being added at this site on Trinity River (CA) to increase geomorphic complexity and bed-material favored by salmon. Photograph courtesy of Nate Bradley, Reclamation.



Figure 14. Looking at sedimentation at Paonia Reservoir that affects intake operations and storage capacity. Reservoir sediment management research could help develop solutions.



Figure 15. Research using Reid-type slot samplers to improve understanding of bed load transport rates on the ephemeral Arroyo de los Piños near Socorro, NM. Photograph courtesy of Kyle Stark, New Mexico Institute of Mining and Technology (Socorro, NM).

9.0 River Habitat Restoration (EN5)

Description: Develop and improve aquatic habitat management solutions and tools that improve the ability to comply with regulatory requirements or mitigation measures assigned to Reclamation programs including channel improvements, floodplain connectivity, channel complexity, and riparian vegetation enhancement.

Coordination Contact: Jennifer Bountry, jbountry@usbr.gov, 303-445-3614, Sedimentation and River Hydraulics Group, Technical Service Center, Bureau of Reclamation, Denver, CO

Number of Funded Projects: 63 research projects funded from 2013 to 2017

R&D Office Knowledge Stream: Fall 2014 “The Knowledge Stream: Ecohydraulics and River Restoration Issue” (<https://www.usbr.gov/research/docs/ks/ks-2015-01.pdf>)

Agency Working Teams and Workshops:

Large Wood Workshop and Roadmap (February 14-16, 2012; Seattle, WA): Technical workshop on large wood applications and research needs in river settings. Individuals from federal, state, and local governments, tribes, universities, and private industry who research, design, and/or implement large wood in river restoration projects attended. A report documenting outcomes from the workshop and a subsequent large wood research roadmap can be found at www.usbr.gov/research/projects/detail.cfm?id=3775.

Stream Restoration Workshop (May 17-19, 2011; Sacramento, CA): Workshop attended by Bureau of Reclamation & U.S. Army Corps of Engineers technical staff. Specific objectives were to (1) review the state of science and engineering as practiced within each agency; (2) recognize pertinent science and technology gaps; and (3) identify opportunities for productive interagency cooperation and collaboration. A summary report was generated that is available by request.

Research Topic List (Highest Priorities in Bold):

This list includes a summary list of research topics described resulting from the surveys described in Section 2.2. The original survey topics were synthesized to organize the ideas into topics or science needs associated with the topics (See Table 2 in Appendix A for more detail on science needs and resources for each topic in the list below). The highest priority topics identified by top 20% of votes or noted as important to all regions are highlighted in the list below in bold.

1. Improve fish screen functionality and efficiency
2. **Develop alternatives that eliminate need for fish screens (PRIORITY)**

3. Develop cost-effective screens for small diversions
4. Improve detection and tracking of movement and migration of individuals and/or species
5. Improve understanding of species survival through large river systems
- 6. Develop ecosystem health indicators throughout watershed (PRIORITY)**
7. Improve understanding of germination, growth, and mortality of riparian vegetation and the corresponding linkages to habitat
- 8. Better understand effects of ecohydraulics on habitat availability, connectivity, and food webs for aquatic species (Figure 16) (PRIORITY)**
9. Improve understanding of movement and distribution patterns of individual animals responding to environmental conditions
10. Determine linkages between local ecosystem habitat modifications and species population changes
11. Enhance strategies to reduce piscivorous (feeding on fish) predation by non-native species
- 12. Improve upstream and downstream fish passage at dams (Figure 17)**
13. Improve economic, ecologic, and engineering tools for evaluating effects and impacts of dam removal on associated river and riparian resources
14. Develop river restoration database to inform future river rehabilitation design
15. Develop river data collection techniques for complex terrains (e.g. log jams, wetlands, swift rivers)
- 16. Evaluate post-construction habitat and design feature performance for rehabilitation projects (PRIORITY)**
17. Integrate habitat requirements into rehabilitation design on watershed, reach, or project scales
18. Evaluate river rehabilitation in urban or heavily modified watersheds
- 19. Improve future channel change predictions in habitat rehabilitation areas and near Reclamation infrastructure (Figure 18) (PRIORITY)**
20. Quantify ecosystem services related to habitat rehabilitation projects
21. Incorporate large wood in numerical models used for rehabilitation design (Figure 19)
22. Improve woody debris management and augmentation in rivers or reservoirs for rehabilitation



Figure 16. Looking at juvenile salmon on Methow River where restoration is being implemented for habitat improvements. Research is needed to determine how restoration projects are performing and improving habitat and life cycle parameters for aquatic species. Photograph courtesy of John Crandall, Methow Salmon Recovery Foundation.



Figure 17. Shasta Dam on the Sacramento River (CA) where high-head fish passage research could help provide future fish passage options.



Figure 18. Research is needed to improve capability to predict river response from constructed habitat features such as this example of a log jam being constructed on the Trinity River. Photograph courtesy of Nate Bradley, Reclamation.

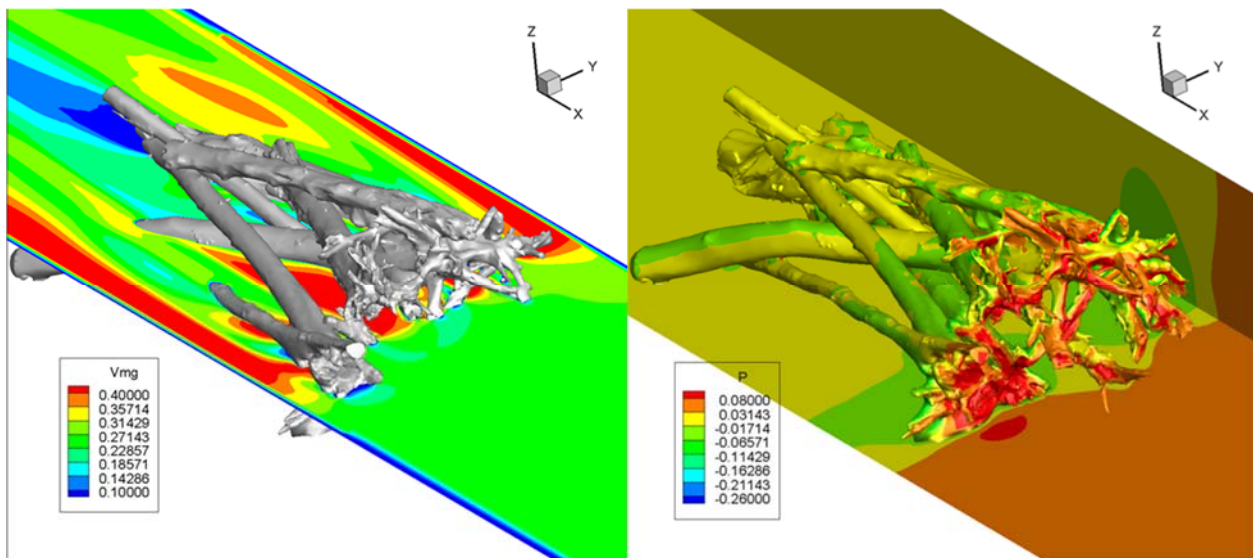


Figure 19. Research modeling of large wood in streams that allows prediction of parameters such as velocity for fish habitat (see left image) and pressure that can be used to analyze structure stability (see right image). Images courtesy of Yong Lai, Reclamation.

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Appendix A: Category tables of research topics, science needs, and resources

Table 2. Expanded description of Water Delivery Reliability (ENI) research topics and needs.

| EN1 Topic Number | Theme | Water Delivery Reliability Topic | Science Need | Topic Resources |
|------------------|-----------------------|---|---|--|
| 1 | Reservoirs | Develop Reclamation-wide database of irrigation, municipal and industrial, and environmental flow deliveries | Database of irrigation, municipal and industrial, and environmental flow deliveries including specific deliveries related to contracts requirements or water operations. | USGS National Water Information System (NWIS) - https://water.usgs.gov/GIS/metadata/usgswrd/XML/nwis_water_use.xml "Western Water Information Network" (2004-2007, S&T project 1201) "Estimating Municipal, Rural, and Industrial Water Requirements" (2004, S&T project 601) |
| 2 | Reservoirs | Increase tools available to meet water needs for environmental flows (e.g. wetlands, riparian zone, aquatic invertebrates, fish and wildlife) | Methods to release flow for groundwater and wetland augmentation. Seasonal wetland best management practices for water conservation. Methods to release flow to establish riparian ecosystems. Methods to release flow to increase aquatic invertebrates. Develop methods to accomplish minimum or seasonal flow releases to benefit fish and wildlife habitat. | Reclamation WaterSMART Reservoir Operations Pilot Initiative - www.usbr.gov/watersmart/ URS (2008). "Evaluation of Wetlands Associated with Reservoir Operations". "Riparian Habitat Establishment Model (RHEM)" (2006, S&T project 3411) and Tansey et al. (2011). "Saving Water and Ensuring Delivery: Flow Prescription and the Discharge to Habitat Relationship for a Listed Anadromous Salmonid" (2007-2010, S&T project 7899). |
| 3 | Reservoirs and Rivers | Use flushing flows for habitat maintenance with recreational uses | Improve understanding of how flushing flows can be used for habitat maintenance. | "Predation on Listed Fishes at Reclamation Facilities and Ways to Reduce Its Impact" (2008-2011, S&T project 7432) |

| EN1 Topic Number | Theme | Water Delivery Reliability Topic | Science Need | Topic Resources |
|------------------------|-----------------------|--|--|--|
| 4 | Reservoirs and Rivers | Modify reservoir operations to better manage temperatures for downstream fisheries* | Operations for cold-water fisheries to reduce the warm afternoon tailwater temperature peaks. | <p>“Climate Change: Application of HydroGeoSphere (HGS) Thermal (Temperature) Modules for Evaluation of the Impacts of Climate Change on Water Resources and Fish Ecosystems” (2010, S&T project 3821)</p> <p>“Seasonal Climate Forecasts for Water Temperature Projections in Reservoirs and Streams” (2006, S&T project 2403)</p> <p>“Using Seasonal Climate Forecasts to Improve Temperature Planning in Reservoirs and Streams” (2007, S&T project 7523)</p> <p>Potential future Reclamation prize competition.</p> |
| 5 | Reservoirs and Rivers | Determine water operations impacts to flow hydrographs and water dependent ecological resiliencies | <p>Effects of reservoir release hydrographs on water dependent ecosystems.</p> <p>Effects of reservoir operations on groundwater and biodiversity, including impact of groundwater recharge projects on reservoirs and ecosystems.</p> | <p>“Effects of Climate Change and Reservoir Operations on Riparian Vegetation” (2014-2016, S&T project 1596).</p> <p>“How Much Flow is Enough? The Effects of Altering Discharge on the Naches River, Washington” (2004-2006, S&T project 61).</p> <p>“Steelhead Habitat Use and Reclamation Operations in the Yakima River, Washington” (2004-2007, S&T project 1125).</p> <p>“Investigation of Reclamation Project Effects and Management Recommendations for Native Fish of the Milk River in Montana Using Innovative Telemetry Techniques” (2004-2009, S&T project 1068).</p> <p>Grand Canyon Research and Monitoring</p> |

| EN1 Topic Number | Theme | Water Delivery Reliability Topic | Science Need | Topic Resources |
|------------------|-----------------------|---|--|---|
| | | | | Center (USGS): https://www.gcmrc.gov/ |
| 6 | Reservoirs and Rivers | Develop methods for environmental flow operations to respond to hydrologic variability | Identify needs for research and tools to predict hydrology coming out of basin studies and pilot reservoir operations programs. | Mateus and Tullos. (2016). "Reliability, Sensitivity, and Uncertainty of Reservoir Performance Under Climate Variability in Basins with Different Hydrogeologic Settings in Northwestern United States". Brekke et al. (2009). "Assessing Reservoir Operations Risk Under Climate Change". |
| 7 | Reservoirs and Rivers | Quantify ecosystem services related to environmental flows | Develop best practices to quantify ecosystem services related to environmental flows. | USGS Science and Decision Center research efforts: www.usgs.gov/sdc/eco_services.html |
| 8 | Reservoirs and Rivers | Improve watershed management to control erosion and flooding | Review guidelines from other agencies such as: USFS, NRCS, local governments and institutions. Develop best practices for watershed management resulting from projects funded under CWMP and WWEP and review of guidelines from other agencies. | "Installing Erosion Control Structures Across a Landscape as a Restoration Treatment and Adaptive Watershed Management Alternative for Climate Change" (2016, S&T ID 720) |
| 9 | Rivers | Develop best practices to implement adaptive management for operations to support environmental restoration | Improve understanding of how to implement adaptive management operations to support environmental restoration. | Williams et al. (2009) "Adaptive Management: The U.S. Department of the Interior Technical Guide". Williams et al. (2012). "Adaptive Management: The U.S. Department of the Interior Applications Guide". |
| 10 | Rivers | Operation strategies to reduce stranding of fish during low and high flows | Identify methods to reduce stranding of fish during low flows, floods, or | |

| EN1 Topic Number | Theme | Water Delivery Reliability Topic | Science Need | Topic Resources |
|------------------------|-------|----------------------------------|--|-----------------|
| | | | regulated high flows due to disconnected rivers/streams. | |

Table 3. Expanded description of Invasive Species (EN2) research topics and needs.

| EN2 Topic Number | Theme | Invasive Species Topic | Science Need | Topic Resources |
|------------------|---------|--|--|---|
| 1 | Control | Determine effective site-specific uses of existing and innovative integrated pest management (IPM) for riparian and aquatic vegetation that reduces flow conveyance or impedes operations (e.g., Phragmites, Eurasian watermilfoil). | <p>Identify effective chemical control methods, including field testing of potential chemicals, to determine the best efficacy with lowest concentration of chemical application without harming non-target species.</p> <p>Determine specific biocontrol agent availability and efficacy in infested environment, including field or lab testing, without harming non-target species.</p> <p>Determine effectiveness of mechanical methods that do not increase spreading, including field trials, without harming non-target species.</p> <p>Determine effectiveness of environmental controls, such as drawdowns, drought, and temperature extremes without harming non-target species.</p> <p>Define invasive species habitat suitability requirements and parameters to predict potential vulnerable sites and infestation distributions.</p> | <p>Integrated Pest Management Manual for Effective Management on Reclamation Facilities (Reclamation 2008)</p> <p>Reclamation Directive and Standard ENV 01-01 for Pest Management/Resource Protection (Integrated Pest Management) Program, DOI Departmental Manual (524 DM 1) for Invasive Species Policy</p> |
| 2 | Control | Determine effective site-specific uses of existing and innovative integrated pest management (IPM) for mussels, fish, birds, mammals, etc. that affect threatened or endangered species or impede operations.* | <p>Identify effective chemical control methods without harming non-target species.</p> <p>Determine specific biocontrol agent availability and efficacy without harming non-target species.</p> <p>Determine effectiveness of mechanical methods that do not increase spreading without harming non-target species.</p> <p>Determine effectiveness of environmental controls, such as drawdowns, drought, and temperature extremes without harming non-target species.</p> | <p>Reclamation Invasive Mussels research: www.usbr.gov/mussels/</p> <p>Reclamation prize competition on “Eradication of Invasive Mussels in Open Water” conducted in FY18.</p> |

| | | | | |
|---|-----------|---|--|--|
| | | | Define invasive species habitat suitability requirements and parameters to predict potential vulnerable sites and infestation distributions. | |
| 3 | Detection | Improve detection, spread prevention, and monitoring methods in order to identify invasive species infestations and reduce range expansion. | <p>Improve Department of Interior Early Detection and Rapid Assessment and Rapid Response (EDRR) to reduce the harm to threatened and endangered species.</p> <p>Improve ability to identify early presence of injurious species on priority landscapes and aquatic areas to promote containment and reduce spread.</p> <p>Develop implementation techniques for unintrusive biologic assessment such as eDNA.</p> | <p>Reclamation Invasive Mussels research: www.usbr.gov/mussels/</p> <p>DOI (2016). "Safeguarding America's Lands and Waters from Invasive Species: A National Framework for Early Detection and Rapid Response"</p> |
| 4 | Impacts | Determine impacts of invasive species and mitigation measures to protect site-specific threatened or endangered species, infrastructure, or operations. | <p>Methods for weed removal from hydraulic structures and management of algal issues.</p> <p>Methods and devices for the prevention of invasive species spread.</p> <p>Methods and guidelines to prevent open niche/niche gap potential or reestablishment.</p> | <p>Reclamation Invasive Mussels research: www.usbr.gov/mussels/</p> |

Table 4. Expanded description of Water Quality (EN3) research topics and needs.

| EN3 Topic Number | Theme | Topic | Science Need | Topic Resources |
|------------------|------------|---|--|---|
| 1 | Operations | Develop database for water quality parameters at Reclamation facilities | Determine appropriate metrics and coordination needs. | Regional reservoir sampling programs (e.g. PN Region's River and Reservoir Operations group). |
| 2 | Operations | Improve methods for water temperature control downstream of dams* | Identify current methods for controlling temperature and scope research needs for new technologies and operational strategies. Review implementation at other facilities outside of Reclamation. | Potential future Reclamation prize competition. Potential pilot sites: Temperature control systems at Shasta, Hungry Horse, Folsom, and Flaming Gorge Dam and flexible temperature curtains at Whiskeytown and Lewiston. |
| 3 | Operations | Improve understanding of operational effects on salinity, temperature, oxygen, turbidity, and nutrient levels in flow releases and in-reservoir processes | Improve modeling techniques and study guidelines. Improve understanding of linkages between reservoir processes and operations (drawdown, wind, tributary inputs, hydrology, and stratification). | Reclamation and Colorado State University. 1993. "Aquatic Ecology Studies of Twin Lakes, Colorado 1971-86." LaBounty and Horn. 1997. "The influence of drainage from the Las Vegas Valley on the Limnology of Boulder Basin, Lake Mead, Arizona Nevada." Bartholow et al. 2001. "Simulated limnological effects of the Shasta Lake temperature control device." |

| EN3 Topic Number | Theme | Topic | Science Need | Topic Resources |
|------------------|------------|---|---|--|
| | | | | |
| 4 | Operations | Improve understanding of operational effects on the transport and level of contaminants and toxic materials | <p>Integrate numerical modeling tools into a comprehensive and reliable predictive model (e.g. mercury cycling process model for reservoirs in MP Region).</p> <p>Identify impaired Reclamation reservoir(s) for data collection and pilot study.</p> <p>Develop method to assess loading from watershed to reservoirs.</p> | |
| 5 | Operations | Reduce gas supersaturation downstream of dams | Develop new technologies to reduce total dissolved gas downstream of dams. | <p>USACE (2005) "Libby Dam Total Dissolved Gas Management Study – Initial Appraisal Report"</p> <p>U.S. Department of Energy (2017) "Water Quality Model Improvements at Columbia and Cumberland Basins": https://energy.gov/sites/prod/files/2017/04/f34/water-quality-modeling-improvements.pdf</p> |
| 6 | Operations | Improve understanding in trade-offs in temperature management for threatened and endangered species | Better tools to help understand how temperature changes for one species impact other species and the aquatic ecosystem. | <p>Grand Canyon Research and Monitoring Center (USGS): https://www.gcmrc.gov/</p> |

| EN3 Topic Number | Theme | Topic | Science Need | Topic Resources |
|------------------|-----------|--|---|---|
| 7 | Hydrology | Develop methods to predict, manage, and monitor effects of hydrologic variability on water quality | <p>Incorporate future hydrologic regimes into existing water quality models.</p> <p>Incorporate sea level fluctuations in estuarine environments into water quality models.</p> | <p>Potential study location: Sacramento-San Joaquin Delta</p> <p>Contra Costa Water District. 2010. "Historical Fresh Water and Salinity Conditions in the Western Sacramento-San Joaquin Delta and Suisun Bay - A summary of historical reviews, reports, analyses and measurements".</p> |
| 8 | Land Use | Improve treatment wetlands or other vegetative remediation technologies to preserve or improve water quality | Improved technologies, implementation and design methods for treatment wetlands. | <p>Potential pilot sites: Shadow Mountain Reservoir in Colorado and San Diego River.</p> <p>Boutwell. 2002. "Water Quality and Plant Growth Evaluations of the Floating Islands in Las Vegas Bay, Lake Mead, Nevada".</p> <p>EPA Wetlands Protection and Restoration: https://www.epa.gov/wetlands/constructed-wetlands</p> <p>USGS publications: https://www.nwrc.usgs.gov/research/nh/wetland_ecosystems.htm</p> |
| 9 | Land Use | Determine best land use practices to improve water quality | Review available guidance and recommend best practices. | NRCS water quality guidance: |

| EN3 Topic Number | Theme | Topic | Science Need | Topic Resources |
|------------------|----------|---|---|--|
| | | | Scoping proposal to understand Reclamation needs. | https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/quality/?cid=stelprdb1044782 |
| 10 | Land Use | Incorporate wildfire risks into water quality assessments | <p>Develop guidance on how to predict and/or mitigate impacts to Reclamation water facilities.</p> <p>Scoping proposal to understand Reclamation needs.</p> | <p>Moody, J.A. and D. Martin, 2004. "Wildfire impacts on reservoir sedimentation in the western United States"</p> <p>USFS Pacific Northwest Research Station: Understanding Fire Effects on the Environment: https://www.fs.fed.us/pnw/research/fire/fire-effects.shtml</p> <p>Water Research Foundation and EPA. 2013. "Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation". Web Report 4482.</p> <p>Writer and Murphy. 2012. "Wildfire Effects on Source-Water Quality—Lessons from Fourmile Canyon Fire, Colorado, and Implications for Drinking-Water Treatment".</p> |

| EN3 Topic Number | Theme | Topic | Science Need | Topic Resources |
|------------------|-----------|---|---|--|
| 11 | Economics | Quantify ecosystem services related to water quality improvements | Best practices to be able to compare preventive measures, restoration options, and quantify benefits. | USGS Science and Decision Center research efforts: www.usgs.gov/sdc/eco_services.html |

Table 5. Expanded description of Sediment Management (EN4) research topics and needs.

| EN4 Topic Number | Theme | Sediment Management Topic | Science Need | Topic Resources |
|------------------|------------|--|--|--|
| 1 | Reservoirs | Estimate future reservoir sedimentation (volume and spatial distribution) to account for storage capacity loss over time | <p>Tool development in water operational models such as RiverWare and CRSS to couple hydrologic and sediment models for planning studies.</p> <p>Influence or sensitivity of reservoir sedimentation to future climate and land use (e.g. floods, wildfire).</p> <p>Methods to account for uncertainty / hydrologic variability in input data.</p> <p>Simplified time-based predictive methods and guidance.</p> | <p>Strand and Pemberton (1982) "Reservoir Sedimentation – Technical Guideline for Bureau of Reclamation"</p> <p>Reclamation (2006) "Erosion and Sedimentation Manual"</p> <p>"Time-based Estimation of Reservoir Sedimentation Impacts" (2016-2017, S&T ID 9072)</p> |
| 2 | Reservoirs | Develop reservoir sedimentation database to track capacity loss and trigger maintenance needs | Improved methods on what triggers to use for management decision-making. | <p>USGS REServoir SEDimentation database (RESSD): https://water.usgs.gov/osw/ressed/</p> <p>"Reservoir Sedimentation Information (RSI) Database Stewardship" (2016-2017, S&T ID 8988 and S&T ID 8961)</p> |
| 3 | Reservoirs | Develop indirect methods to estimate reservoir sedimentation* | <p>Process and model improvement (e.g. watershed and sediment yield models), guidance documents.</p> <p>Remote sensing tools.</p> | <p>Reclamation prize competition on "Indirect Estimates of Reservoir Water Storage" conducted in 2017.</p> <p>"Using Beryllium-10 Derived Erosion Rates as a Proxy for Reservoir Sedimentation" (2017, S&T ID 1792)</p> |

| EN4 Topic Number | Theme | Sediment Management Topic | Science Need | Topic Resources |
|------------------|------------|---|---|---|
| | | | | <p>"Reservoir Sediment Prediction over the Western U.S." (2015 and 2017, S&T ID 1752)</p> <p>"Use of a Continuous Simulation, Process-Based Model to Predict Sediment Inflow in Unsurveyed Reservoirs" (2015, S&T ID 8653)</p> |
| 4 | Reservoirs | Improve understanding and guidance of reservoir operation effects on upstream channel response, including water table changes | <p>Process generally known and can be modeled, but continued model development may be helpful.</p> <p>Validation and verification with case studies and development of guidance.</p> | <p>"Pilot Studies of Reservoir Sustainability Options - Flushing and Sluicing" (2016-2017, S&T ID 8235)</p> <p>"Pilot Studies of Reservoir Sustainability Options - Large Reservoirs" (2016-2017, S&T ID 9344)</p> <p>Strand and Pemberton (1982) "Reservoir Sedimentation – Technical Guideline for Bureau of Reclamation"</p> |
| 5 | Reservoirs | Improve reservoir surveying technology and uncertainty quantification | Review new technologies (e.g. AUVs) and develop methods to quantify uncertainty and bias in different survey techniques. | |
| 6 | Reservoirs | Improve understanding and practices of how sediment transport and sediment augmentation interacts with channel morphology to create topographic complexity important for downstream habitat | Linking restoration design, sediment transport analysis, gravel augmentation, and hydrology to predict (or monitor) sediment related habitat metrics through numerical modelling of case studies and/or restoration project monitoring. | "Can a Numerical Model Simulate Observed Patterns of Gravel Dispersion Based on River Bed Morphology and Flow Hydraulics" (2015-2017, S&T ID 5049) |

| EN4 Topic Number | Theme | Sediment Management Topic | Science Need | Topic Resources |
|------------------|------------------------|---|---|--|
| 7 | Reservoirs | Improve effectiveness of reservoir sediment dredging/management technologies to improve sustainability* | Development of new techniques or improvement in the effectiveness of existing reservoir sediment dredging/management technologies. | Potential future Reclamation prize competition. |
| 8 | Reservoirs / economics | Develop economics of sustainable reservoir sediment management | Application of a life-cycle economic approach to infrastructure and sediment management. | "Application of New Discounting Approaches for Long-Lived Water Resource Investments" (2015, S&T ID 9994) |
| 9 | Reservoirs and Rivers | Improve estimates of sediment contributions from tributaries, especially from ephemeral systems | Sediment transport equations significantly underestimate the rate of transport for ephemeral streams. Hydraulic and sediment transport datasets need to be collected and synthesized. Better understanding of long-term yield needed, not just flow relationships but also magnitude-frequency of floods in ephemeral streams. | "Ephemeral Tributary Sediment Transport Measurement" (2015-2017, S&T ID 9781) "Using Beryllium-10 Derived Erosion Rates as a Proxy for Reservoir Sedimentation" (2017, S&T ID 1792) |
| 10 | Reservoirs and Rivers | Enhance prediction tools to better manage sedimentation (flush fines, build sediment bars, gravel augmentation) | Additional model development with multi-dimensional models to predict pressure flushing and prediction of downstream gravel augmentation. | Huang, J.V., Greimann, B. (2012). Sedimentation and River Hydraulics – One Dimension, Version 3.0 Lai, Y.G. 2008. SRH-2D version 2: Theory and User's Manual. |
| 11 | Reservoirs and Rivers | Improve monitoring methods to track sediment released from reservoirs and associated impacts | New technologies, assessment/calibration of existing technologies. | "Elwha Impact Plate System – Accelerometers" (2016-2017, S&T ID 6209) |

| EN4 Topic Number | Theme | Sediment Management Topic | Science Need | Topic Resources |
|------------------|-----------------------|---|--|---|
| | | | | <p>"Measuring Bedload with Hydrophones" (2016-2017, S&T ID 7906)</p> <p>"Field Testing and Calibration of a Hydrophone System for Surrogate Bedload Measurement" (2015, S&T ID 9342)</p> <p>"Seismic Monitoring of Bedload Transport in Large Gravel-bed Rivers" (2015, S&T ID 5561)</p> <p>"Investigating Feasibility of Acoustic Doppler Methods for Monitoring Suspended Sediment" (2017, S&T ID 1777)</p> |
| 12 | Reservoirs and Rivers | Quantify ecosystem services related to sediment management actions | Develop best practices to quantify ecosystem services related to sediment management. | USGS Science and Decision Center research efforts: www.usgs.gov/sdc/eco_services.html |
| 13 | Reservoirs and Rivers | Develop solutions for managing sediment transport and deposition associated with dam removal or sediment sluicing | <p>Model development, best practices, and case studies.</p> <p>Monitoring and model validation of relevant completed projects.</p> | <p>Randle, T. and Bountry, J. (2017 in review). Dam Removal Analysis Guidelines for Sediment.</p> <p>Huang, J.V., Greimann, B. (2012). Sedimentation and River Hydraulics – One Dimension, Version 3.0</p> |

| EN4 Topic Number | Theme | Sediment Management Topic | Science Need | Topic Resources |
|------------------|--------|---|---|---|
| 14 | Rivers | Improve methods to reduce sediment from water supply intakes, screens, and diversions | New technologies needed. Technologies are dated with few recent improvements since the use/application of Iowa Vanes, Coanda Screens, sluiceways, etc. | Wahl (2003) "Design Guidance for Coanda-Effect Screens". Odgaard et al. (1990). "Hydraulic Laboratory Model Study of River Intake at Duane Arnold Energy Center". Melone et al. (1975). "Exclusion and Ejection of Sediment from Canals". |
| 15 | Rivers | Improve methods to control wetland inflow-sediment management | Best practices approaches regarding siting and design. Scope existing methods and future research needs. | |
| 16 | Rivers | Improve design and modeling techniques for side channel reconnection and determining sediment impacts | Improve application capabilities of multi-dimensional models. Develop indexes of bedload/sand transport in a system and relative risk of side channel filling/abandonment. Improve/develop design methods and guidelines. | |
| 17 | Rivers | Restore estuaries and floodplains that have been heavily manipulated by dikes/levees or other human actions | Improve/develop guidelines. | |

Table 6. Expanded description of River Habitat Restoration (EN5) research topics and needs.

| EN5 Topic Number | Theme | River Habitat Restoration Topic | Science Need | Topic Resources |
|------------------|--------------|--|---|---|
| 1 | Fish screens | Improve fish screen functionality and efficiency* | <p>Methods to reduce sediment and debris clogging near fish screen.</p> <p>Methods to minimize entrainment of larvae and eggs near fish screen.</p> <p>Methods to better distribute flow across the screen.</p> | <p>Anadromous Fish Screen Program (Reclamation-USFWS): https://www.fws.gov/cno/fisheries/cvpia/AnadromFishScreen.cfm</p> <p>Federal and state fish screening guidelines (e.g. NMFS 1997, NMFS 2011)</p> <p>Bureau of Reclamation (2006). Fish Protection at Water Diversions.</p> <p>“Investigation of Fish Screen Cleaning by Air Burst and Water Jet Systems”. (2017, S&T project 1710).</p> <p>“Improving Data Collection Methods for Hydraulic Evaluations of Fish Screens”. (2016, S&T project 6504).</p> <p>Heiner and Mefford (2011). “Physical Hydraulic Modeling of Secondary Louver Replacement at the Tracy Fish Collection Facility”.</p> |
| 2 | Fish screens | Develop alternatives that eliminate need for fish screens* | New technologies such as. infiltration galleries, non-physical barriers. | <p>Bureau of Reclamation (2006). Fish Protection at Water Diversions.</p> <p>“Exploring Techniques to Reduce Lamprey and Salmonid Entrainment into Canals” (2016-2018, S&T project 2621)</p> |

| EN5 Topic Number | Theme | River Habitat Restoration Topic | Science Need | Topic Resources |
|------------------|--------------|--|--|---|
| | | | | <p>“Evaluation of Hogback Diversion Canal Fish Weir on Adult and Larval Fish” (2016-2017, S&T project 1618) and “Evaluating an Innovative Fish Weir for Preventing Fish Entrainment” (2015, S&T project 5166)</p> <p>“Literature Review of Electric Barriers for Returning Adult Salmonids” (2014, S&T project 9447)</p> <p>“Effectiveness of a Delta Cross Channel Graduated Field Electrical Fish Barrier to Reduce Movement of Adult Fall-run Chinook Salmon from the Mokelumne River into the Sacramento River, CA” (2015, 2017, S&T project 554)</p> <p>“Non-Physical Barrier (NPB) for Fish Protection Evaluation: Can an Inexpensive Barrier Be Effective for Threatened Fish?” (2009-2010, S&T project 8740)</p> <p>Bowen et al. 2009. “Effectiveness of a Non-Physical Fish Barrier at the Divergence of the Old and San Joaquin Rivers (CA)”.</p> |
| 3 | Fish screens | Develop cost-effective fish screens for small diversions | New technologies with low-cost implementation. | <p>Anadromous Fish Screen Program (Reclamation-USFWS): https://www.fws.gov/cno/fisheries/cvpia/AnadromFishScreen.cfm</p> <p>Kavvas et al. (2010, 2013). “Assessing Hydraulics and Juvenile Chinook Salmon</p> |

| EN5 Topic Number | Theme | River Habitat Restoration Topic | Science Need | Topic Resources |
|------------------|------------------------------|---|---|--|
| | | | | Behavior and Swimming Performance Near Unscreened Diversions on the Sacramento River: Large Flume Simulations” |
| 4 | Species tracking | Improve detection and tracking of movement and migration of individuals and/or species* | <p>Identify individual fish using fish recognition algorithms.</p> <p>Improve ability to detect and receive acoustic fish tag transmissions.</p> <p>Improve detection read range and detection accuracy (limit interference) of passive integrated transponder fish tags.</p> <p>Improve radio and acoustic telemetry tag systems by increasing tag life expectancy, reducing tag size, determining mortality, and/or reducing system costs.</p> <p>Develop ways to remotely activate and deactivate fish tags.</p> | Reclamation prize competition on “New Concepts in Remote Fish Detection” conducted in 2015. |
| 5 | Species habitat and survival | Improve understanding of species survival through large river systems | <p>Improve understanding of triggers for predation zones and other factors impacting survival.</p> <p>Perform field studies to monitor fate of individual fish.</p> | <p>Grossman et al. 2013. “Effects of fish predation on salmonids in the Sacramento River–San Joaquin Delta and associated ecosystems.”</p> <p>Grossman. 2016. “Predation on Fishes in the Sacramento-San Joaquin Delta: Current Knowledge and Future Directions”.</p> <p>California Department Fish and Wildlife, Delta Science Program, and National Marine Fisheries Service. 2013 “State of the Science Workshop on Fish Predation on</p> |

| EN5 Topic Number | Theme | River Habitat Restoration Topic | Science Need | Topic Resources |
|------------------|------------------------------|--|---|---|
| | | | | Central Valley Salmonids in the Bay-Delta Watershed". |
| 6 | Species habitat and survival | Develop ecosystem health indicators throughout watershed | Review of existing literature and determination of science needs and application potential for Reclamation programs. | |
| 7 | Species habitat and survival | Improve understanding of germination, growth, and mortality of riparian vegetation and the corresponding linkages to habitat | Improve model capability and field data linkages. Improve understanding of river stage and moisture available to riparian species (saturated and unsaturated). | Siegle et al. 2017. "Elephant Butte Sediment Plug Baseline Studies: Annual Report 2016". Siegle et al. 2017. "Bosque del Apache Sediment Plug Baseline Studies: Annual Report 2016". Greimann, B. P., 2016. "Modeling Riparian Vegetation on Sacramento River with SRH-1DV" Huang, J.V., 2016. "SRH-1DV Vegetation Modeling of the Trinity River between Lewiston Dam and the North Fork Trinity River Huang, J.V., 2015. SRH-1DV Vegetation Modeling of the San Joaquin River from Hwy 99 to Chowchilla Bypass |
| 8 | Species habitat and survival | Better understand effects of ecohydraulics on habitat availability, connectivity, and food webs for aquatic species | Validation of existing monitoring and predictive models including "habitat suitability index (HSI)" and instream flow methods. Research using more complex food web or GIS based parameters. | Reclamation prize competition on "Quantifying Drift Invertebrates in River and Estuary Systems" conducted in 2015. "Evaluating the Cost Effectiveness of Data Collection Techniques and Relative |

| EN5 Topic Number | Theme | River Habitat Restoration Topic | Science Need | Topic Resources |
|------------------|-------|---------------------------------|--|---|
| | | | <p>Improve methods to quantify instream habitat considering additional parameters beyond hydraulics such as predators, food availability, water temperature, and vegetation cover.</p> <p>Determination of best indicator variables.</p> | <p>Improvements in Modeling Reservoir Production" (2009-2011, S&T project 7622)</p> <p>Huang and Bountry (2014). "Evaluating Climate-Induced Runoff and Temperature Change on Stream Habitat Metrics for Endangered or Threatened Fish"</p> <p>Bellmore et al. (2016). Incorporating food web dynamics into ecological restoration: a modeling approach for river ecosystems</p> <p>Research model description at http://isemp.org/projects/qrf-models/</p> <p>American Fisheries Society 145th Annual Meeting, August 16 to 20, 2015, Recent Advances in Establishing Fish-Habitat Relationships in Lotic Systems: https://afs.confex.com/afs/2015/webprogram/Session3524.html</p> <p>Raleigh et al. (1984 and 1986) Habitat suitability information: Rainbow trout & Habitat suitability index models and instream flow suitability curves: chinook salmon.</p> <p>Beecher and Caldwell (2013) Instream flow study guidelines by Washington Department of Ecology: Technical and Habitat Suitability Issues including fish preference curves.</p> |

| EN5 Topic Number | Theme | River Habitat Restoration Topic | Science Need | Topic Resources |
|------------------|------------------------------|--|--|---|
| 9 | Species habitat and survival | Improve understanding of movement and distribution patterns of individual animals responding to environmental conditions | Improve ability to analyze and forecast critical habitat utilization that can incorporate logic of individual animals behavior. | Goodwin et al. (2006). "Forecasting 3-D Fish Movement Behavior Using a Eulerian-Lagrangian-Agent Method (ELAM)" |
| 10 | Species habitat and survival | Determine linkages between local ecosystem habitat modifications and species population changes | Better methods to analyze available data and quantify effects of local project data. Methods to address scale dependency and restoration efforts that can take multiple years to implement. | Regional monitoring programs and research (e.g. PN Region's Federal Columbia River Power System Biological Opinion Tributary Habitat Program, UC Region's Rio Grande avian studies). |
| 11 | Species habitat and survival | Enhance strategies to reduce piscivorous (feeding on fish) predation by non-native species* | Methods to reduce predator abundance via biocontrols, toxicants, direct elimination. Methods to reduce predation without harming predators that are important sport fish (e.g. lighting, water cannons, appetite suppression, refugia). | Potential future Reclamation prize competition. Central Valley Project Improvement Act - "Assess Impacts of River Structure Lighting" Horn (2016). "Sankey Refugia Screen Panel Test, 2015-2016 Report of Findings (DIDSON-ARIS)" California Department of Water Resources. 2010. "Release Site Predation Study". CVPIA's Science Integration Team - Salmon life cycle Decision Support Models (DSMs) |
| 12 | Fish passage | Improve upstream and downstream fish passage at dams* | Develop innovative passage improvements and alternatives for threatened and endangered species. | Reclamation prize competition on "Downstream Fish Passage at Tall Dams" conducted in 2017. |

| EN5 Topic Number | Theme | River Habitat Restoration Topic | Science Need | Topic Resources |
|------------------|-----------------------|--|--|--|
| | | | <p>Methods to improve attraction/guidance to passage location, particularly in large reservoirs.</p> <p>Methods to improve fish capture capture efficiencies.</p> <p>New technologies or techniques to reduce costs of large passage structures.</p> <p>New technologies with specific application to tall dams.</p> <p>New design guidelines for species of concern that lack existing guidelines (e.g. Cui Ui on Truckee River).</p> | <p>California Department of Water Resources (2013) "Technologies for Passing Fish at High Head Dams".</p> <p>"Researching a Concept for a Self-Regulating Articulated Fishway" (2013, S&T project 9548)</p> <p>"Underwater Curtain Technology for Enhancing Downstream Fish Passage in Storage Reservoirs" (2012, S&T project 6884).</p> <p>"Helix Downstream Fish Passage Design" (2015, S&T project 3437).</p> |
| 13 | Dam removal | Improve economic, ecologic, and engineering tools for evaluating effects and impacts of dam removal on associated river and riparian resources | Economic analysis associated with water quality impacts and benefits from dam removal. | <p>Randle and Bountry (2017 in review). Dam Removal Analysis Guidelines for Sediment.</p> <p>USSD (2015). "Guidelines for Dam Decommissioning Projects"</p> |
| 14 | Rehabilitation design | Develop river restoration database to inform future river rehabilitation design | Evaluate past river restoration projects in variety of programs and river conditions to compare and contrast successes and lessons learned to help inform what type of data base would be useful to share. | Contact Reclamation restoration program coordinators. |
| 15 | Rehabilitation design | Develop river data collection techniques for complex terrains (e.g. log jams, wetlands, swift rivers) | Develop cost effective applications with side scan technology, ground LiDAR, structure for motion, unmanned aerial vehicles (UAVs), and remotely operated underwater vehicles (ROVs). | Reclamation Unmanned Aerial System (UAS) Team. |

| EN5 Topic Number | Theme | River Habitat Restoration Topic | Science Need | Topic Resources |
|------------------|-----------------------|---|---|--|
| 16 | Rehabilitation design | Evaluate post-construction habitat and design feature performance for rehabilitation projects | Identify metrics that improve ability to compare design feature performance for a variety of river settings. | Design Review of Fort Worth District Stream Mitigation Bank Sites (Holste and Sixta, 2016) Contact Reclamation restoration program coordinators. |
| 17 | Rehabilitation design | Integrate habitat requirements into rehabilitation design on watershed, reach, or project scales | Better techniques to integrate species requirements into design process. | |
| 18 | Rehabilitation design | Evaluate river rehabilitation in urban or heavily modified watersheds | Better design methods and guidelines. | "Design of Low-flow Ecosystem Features for Urban Flood Control Structures" (2017-2018, S&T project 1726). U.S. Army Corps of Engineers (2013). "Los Angeles River Ecosystem Restoration – Integrated Feasibility Report". |
| 19 | Rehabilitation design | Improve future channel change predictions in habitat rehabilitation areas and near Reclamation infrastructure | Improve modeling techniques to incorporate channel migration, bank erosion, aggradation, and scour changes in response to proposed design features or infrastructure modifications. | Bank Stabilization Design Guidelines (Baird et al., 2015) Managing Infrastructure in the Stream Environment (Sholtes et al., 2017) |
| 20 | Rehabilitation design | Quantify ecosystem services related to habitat rehabilitation projects | Develop best practices to quantify ecosystem services related to sediment management. | USGS Science and Decision Center research efforts: www.usgs.gov/sdc/eco_services.html |

| EN5 Topic Number | Theme | River Habitat Restoration Topic | Science Need | Topic Resources |
|------------------|------------|--|--|---|
| | | | | USFS Ecosystem Services Team page: https://www.fs.fed.us/pnw/about/programs/gsv/es.shtml |
| 21 | Large wood | Incorporate large wood in numerical models used for rehabilitation design | Continue testing for 2D and 3D models to better represent large wood and assess stage increases. | <p>“Quantitative Modeling Tools of Scour and Morphological Impact due to Large Wood Debris Structures” (2014-2016, S&T project 4495)</p> <p>“Representation of Large Wood Structures Using a Two-Dimensional Model” (2017-2018, S&T project 1756)</p> <p>Bureau of Reclamation and U.S. Army Corps of Engineers. 2016. “National Large Wood Manual”.</p> |
| 22 | Large wood | Improve woody debris management in reservoirs to maximize augmentation opportunities in downstream river | Design tools to limit wood from damaging infrastructure and passing wood to facilitate habitat development and riparian vegetation growth. | <p>“Technical Workshop on Large Wood Applications and Research Needs in River Settings” (2012, S&T project 3775)</p> <p>Bureau of Reclamation and U.S. Army Corps of Engineers. 2016. “National Large Wood Manual”.</p> <p>Knutson and Fealko. 2014. “Large Woody Material – Risk Based Design Guidelines”.</p> <p>USDA Forest Service National Stream & Aquatic Ecology Center</p> |

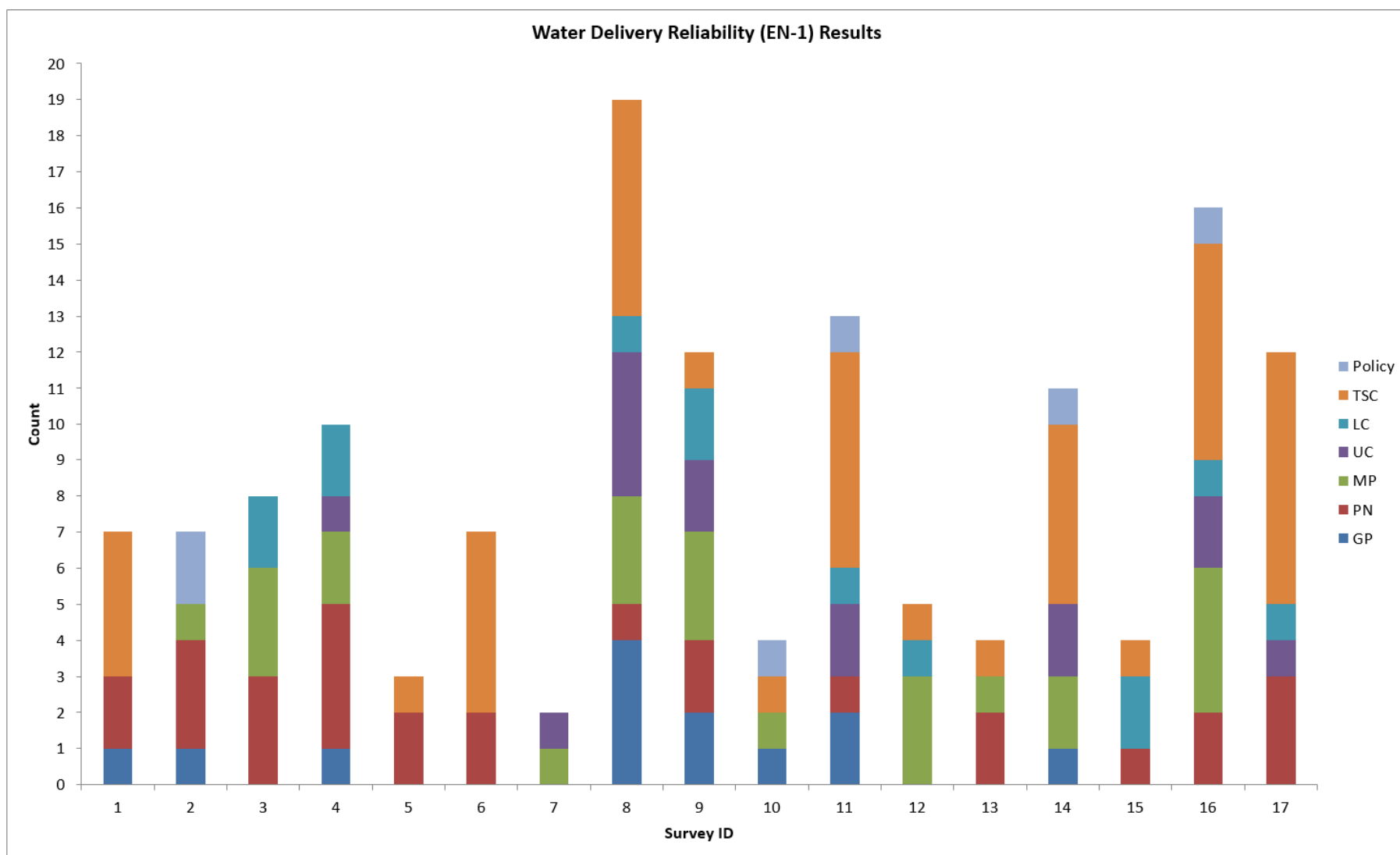
| EN5 Topic Number | Theme | River Habitat Restoration Topic | Science Need | Topic Resources |
|------------------|-------|---------------------------------|--------------|--|
| | | | | www.fs.fed.us/biology/nsaec/products-tools.html |

Appendix B: Research Topic Survey Results

This section contains the list of EN survey topics provided to Reclamation voters along with voting results categorized by Reclamation offices: Policy and Administration (Policy), Technical Service Center (TSC), Lower Colorado Regional Office (LC), Upper Columbia Regional Office (UC), Mid-Pacific Regional Office (MP), Pacific Northwest Regional Office (PN), and Great Plains Regional Office (GP). Topics were generated by Survey #1 and then provided to Reclamation staff across the agency. Survey participants were given the option to add new research ideas that were not already included in the list of topics provided (designated by NEW in lists below). The survey topics and NEW additions were synthesized into the research topics and science needs presented in the main report and Appendix A.

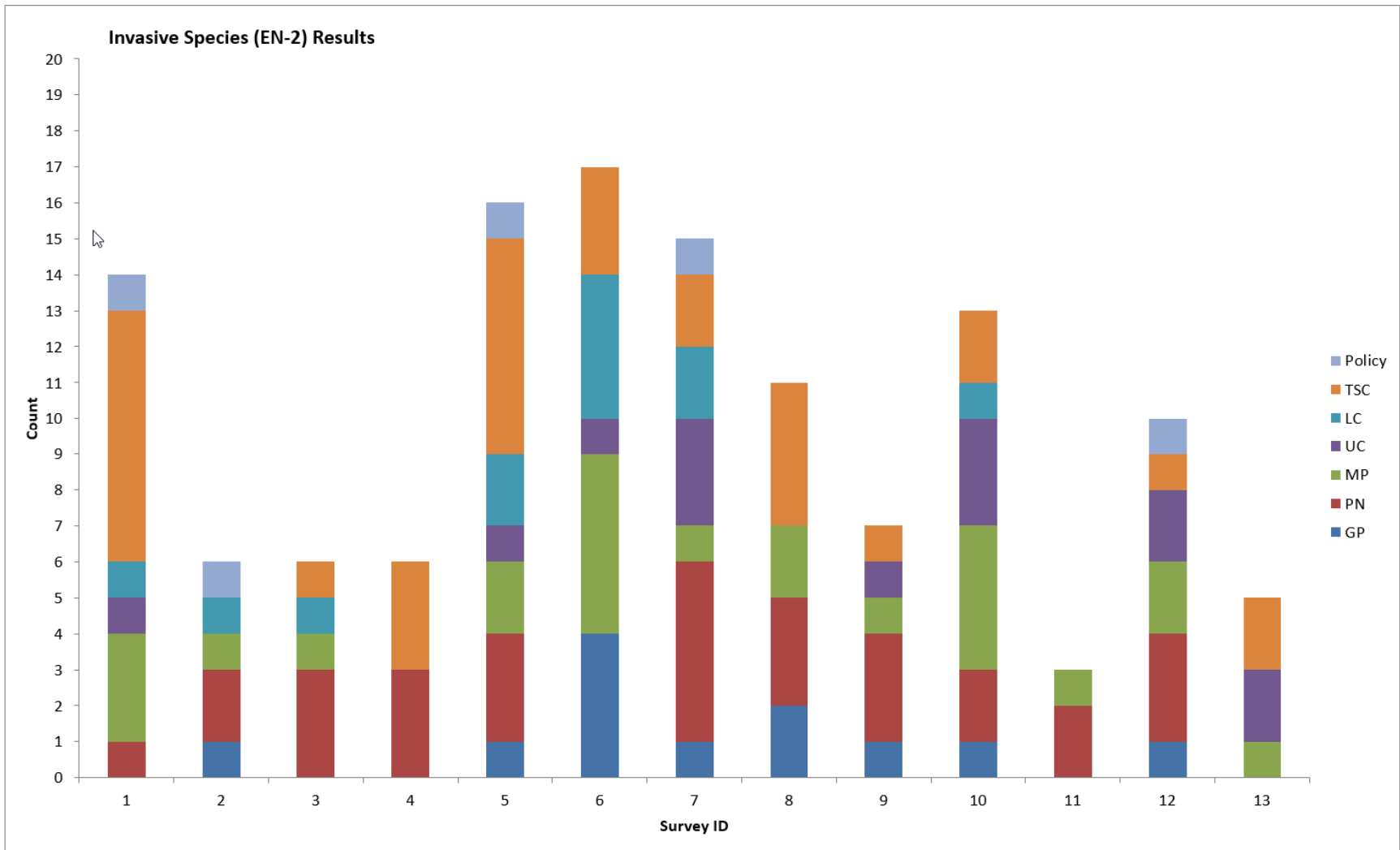
EN1 Survey Topics

1. Database of irrigation, municipal and industrial, and environmental flow deliveries
 2. Reservoir operation effects on groundwater and biodiversity
 3. Methods to release flow for groundwater or wetland augmentation
 4. Methods to release flow to establish riparian ecosystems
 5. Methods to release flow to increase aquatic invertebrates
 6. Flushing flows for habitat maintenance with recreational uses
 7. Monitor food resources for aquatic and terrestrial species
 8. Use adaptive management for operations to support environmental restoration
 9. Minimum or seasonal flow releases to benefit fish and wildlife habitat
 10. Operations for cold-water fisheries to reduce the warm afternoon tailwater temperature peaks
 11. Water operations impacts to flow hydrographs and water dependent ecological resiliencies
 12. Identify methods to reduce stranding of fish during floods or regulated high flows.
 13. Methods to minimize impacts during maintenance of infrastructure to threatened and endangered species
 14. Methods for environmental flow operations to respond to hydrologic variability
 15. Storage and management of emergency spill equipment
 16. Best practices to quantify ecosystem services related to environmental flows
 17. Best practices for watershed management to control erosion and flooding
- NEW: If we could update authorizations at reservoirs to increase tools available to both meet water needs and provide environmental flows
- NEW: Review of technology methods for controlling AIS



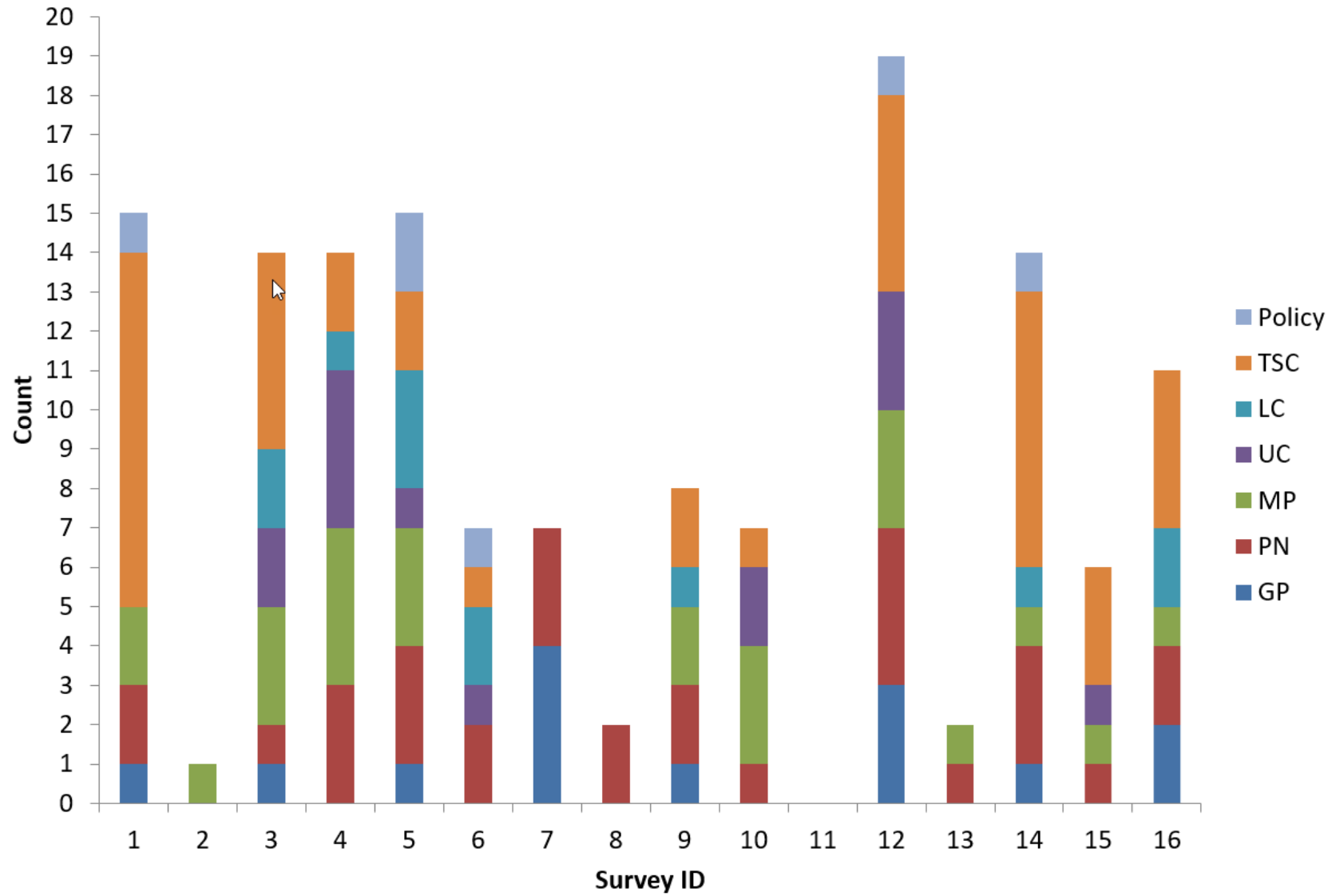
EN2 Survey Topics

1. Improve control methods to prevent spread and impacts related to riparian and aquatic vegetation that reduces flow conveyance or impedes operations (e.g., Phragmites, Eurasian watermilfoil, etc.).
 2. Identify effective chemical control methods, including field testing of potential chemicals to determine the best efficacy with lowest concentration of chemical application.
 3. Determine specific biocontrol agent availability and efficacy in infested environment including field or lab testing.
 4. Determine effectiveness of mechanical methods that do not increase spreading, including field trials.
 5. Determine effectiveness of environmental controls, such as drawdowns, drought, and temperature extremes.
 6. Improve control methods to prevent spread and impacts related to invasive species such as mussels, fish, birds, mammals, etc. that affect threatened or endangered species or impede operations (varies by region and time).
 7. Determine effective chemical, biological, mechanical control, and environmental parameters methods without harming nontarget species.
 8. Improve Department of Interior Early Detection and Rapid Assessment and Rapid Response (EDRR) to reduce the harm to threatened and endangered species.
 9. Develop implementation techniques for unintrusive biologic assessment such as eDNA
 10. Determine ways to limit the impacts of non-native species to threatened and endangered species
 11. Weed removal from hydraulic structures and management of algal issues
 12. Methods and devices for the prevention of invasive species spread
 13. Methods and guidelines to prevent open niche/niche gap potential or reestablishment
- NEW: Control technologies for mussels that can be used by irrigation districts/municipalities; cost effectiveness of watercraft inspection and decontamination vs installation of control technologies for invasive mussels
- NEW: Determine protective strategies and equipment to use during inland oil spills.



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| EN3 Survey Topics |
| 1. Database for water quality parameters at Reclamation facilities |
| 2. Metal analysis database for response to HAZMAT metal release incidents to use as background for cleanup and risk assessment |
| 3. Implement/obtain open data service related to environmental data |
| 4. Methods to control water temperatures downstream of dams |
| 5. Operation effects on salinity, temperatures, and nutrient levels in flow releases |
| 6. Operation effects on the transport and level of contaminants and toxic materials |
| 7. Technologies to reduce gas supersaturation downstream of dams |
| 8. Methods to minimize impacts to threatened or endangered species when applying protective coatings to infrastructure |
| 9. Improve use of treatment wetlands or other vegetative remediation technologies. |
| 10. Improve understanding of trade-offs in temperature management for threatened and endangered species |
| 11. Water operations impacts to flow hydrographs and water dependent ecological resiliencies |
| 12. Effects of hydrologic variability on water quality characteristics |
| 13. Effects of hydrologic variability and sea level rise to water quality in estuarine environments |
| 14. Develop land use practices (on Reclamation lands) to improve water quality |
| 15. Develop guidance for incorporating wildfire risks into water quality assessments |
| 16. Best practices to quantify ecosystem services related to water quality improvements |
| NEW: Coordinate with EPA in developing inland area geographic response plans. |

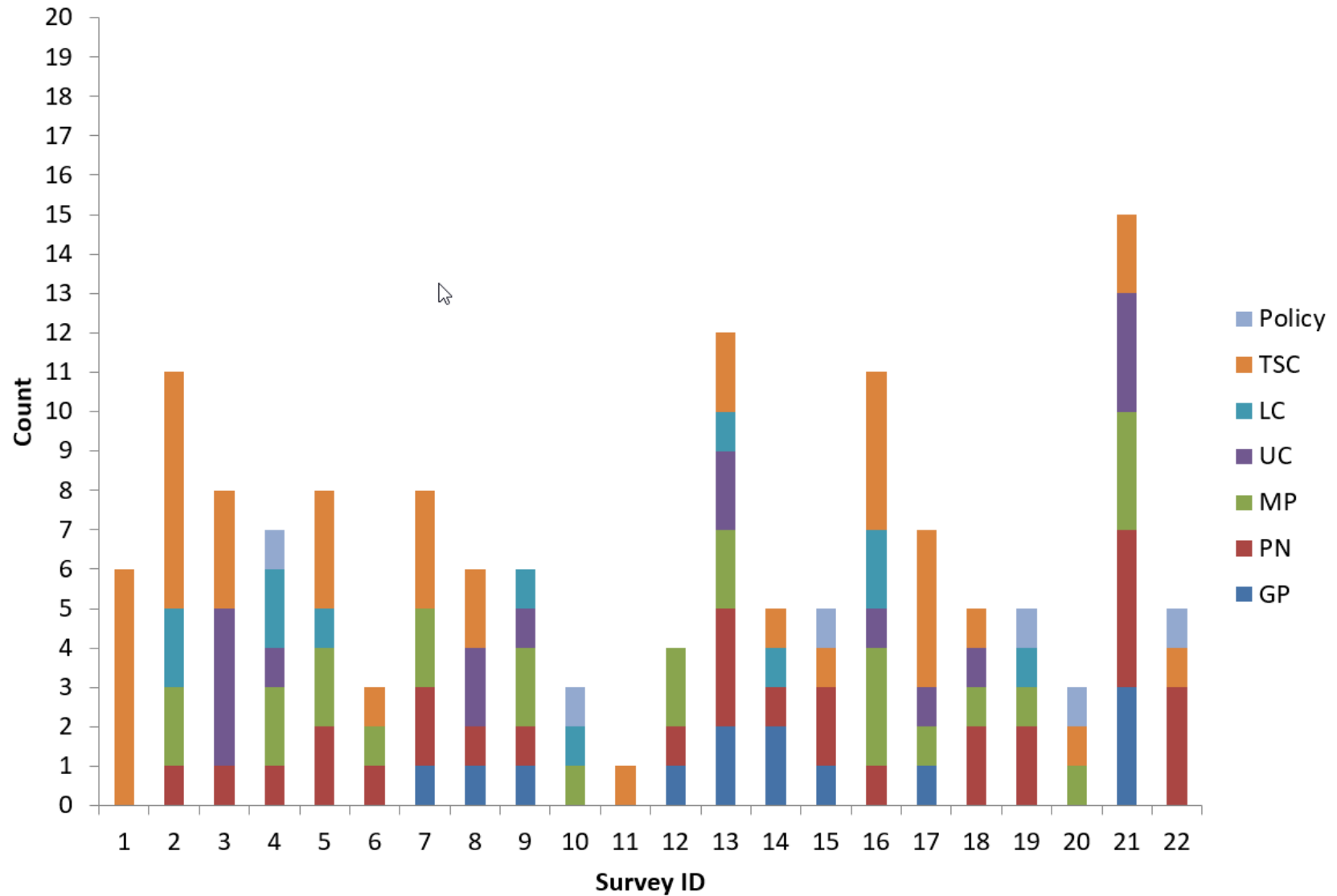
Water Quality (EN-3) Results



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| EN4 Survey Topics |
| 1. Reservoir sedimentation database to track capacity loss and trigger maintenance needs |
| 2. Methods to indirectly estimate reservoir sedimentation |
| 3. Improve estimates of sediment contributions from tributaries especially from ephemeral systems |
| 4. Improve understanding of reservoir operation effects on upstream channel sedimentation |
| 5. Methods to exclude sediment from water supply intakes, screens, and diversions |
| 6. Methods to control wetland inflow-sediment management |
| 7. Prediction tools to better manage sedimentation (flush fines, build sediment bars, gravel augmentation) |
| 8. Improve reservoir surveying technology and uncertainty quantification |
| 9. Monitoring methods to track sediment released from reservoirs and associated impacts |
| 10. Reservoir sediment management plans that address potential contaminants release with fine sediments |
| 11. Time-based methods for prediction of sediment effects |
| 12. Improve modeling techniques for determining sediment impacts of side channel reconnection |
| 13. Improve understanding of how bed material transport interacts with existing channel morphology to create topographic complexity important for habitat |
| 14. Effectiveness of reservoir sediment dredging/management technologies to improve sustainability |
| 15. Economics of sustainable reservoir sediment management |
| 16. Watershed management practices to reduce high rates of sediment erosion and incoming loads to reservoirs |
| 17. Hydrologic variability effects on reservoir sedimentation rates and volumes |

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| 18. Hydrologic variability risks on river restoration projects such as filling of side channels and wetlands |
| 19. Guidelines to restore estuaries that have been heavily manipulated by diking or other human actions |
| 20. Guidelines to manage sediment where channel aggradation is causing a higher water table |
| 21. Best practices for sediment augmentation to improve downstream habitat and channel complexity |
| 22. Quantify ecosystem services related to positive sediment sustainability or management actions |
| Coordinate with EPA in developing geographic response plans. (Duplicate of EN-3 so not counted here) |

Sediment Management (EN-4) Results



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| EN5 Survey Topics |
| 1. Identify data fields or metrics for a river database to inform river rehabilitation design |
| 2. Improve cost effectiveness and accuracy of river data collection techniques for complex terrains (e.g. log jams, wetlands, swift rivers) |
| 3. Plots of fish refuge volume versus time in reservoirs |
| 4. Improve fish screens by reducing sediment and debris clogging, minimizing entrainment of larvae and eggs, and better distributing flow across the screen |
| 5. Study alternatives that eliminate need for fish screens (e.g. infiltration galleries, non-physical barriers) |
| 6. Cost-effective screens for small diversions |
| 7. Solutions for evaluating and managing sediment transport and deposition associated with dam removal |
| 8. Detect and track movement and migration of individual species |
| 9. Identify individual fish using fish recognition algorithms |
| 10. Improve ability to detect and receive acoustic fish tag transmissions |
| 11. Improve detection read range and detection accuracy (limit interference) of passive integrated transponder fish tags |
| 12. Improve radio and acoustic telemetry tag systems by increasing tag life expectancy, reducing tag size, determining mortality, and/or reducing system costs |
| 13. Develop ways to remotely activate and deactivate fish tags |
| 14. Determine species survival through large river systems by monitoring fate of individual fish |
| 15. Develop ecosystem health indicators (including continuity) |
| 16. Identify metrics of habitat and design feature performance for rehabilitation projects |

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| 17. How to use habitat requirements of threatened and endangered species to guide rehabilitation design processes on watershed, reach, or project scales |
| 18. Improve upstream and downstream fish passage at tall dams |
| 19. Develop innovative passage improvements and alternatives for threatened and endangered species |
| 20. Threatened and endangered species migration into newly opened areas as a result of dam removal or modifications (e.g. fish ladders) |
| 21. Economic, ecologic, and engineering tools for evaluating effects and impacts of dam removal on associated river and riparian resources |
| 22. Strategies to reduce piscivorous predation by non-native species |
| 23. Representation of large wood in numerical models used for rehabilitation design |
| 24. Methods for simulating the growth and mortality of riparian vegetation and the corresponding linkages to habitat |
| 25. Methods for quantifying instream habitat for aquatic species |
| 26. Understanding of ecohydraulics and the effects on habitat availability and food webs |
| 27. Woody debris management and augmentation in rivers or reservoirs for rehabilitation |
| 28. Methods to accomplish river rehabilitation in urban or heavily modified watersheds |
| 29. Model critical habitat systems to analyze and forecast the movement and distribution patterns of individual animals responding to environmental conditions |
| 30. Improve methods for predicting future channel change in habitat rehabilitation areas and near Reclamation infrastructure |
| 31. Connect ecosystem habitat modifications to species population changes |
| 32. Guidelines for channel and floodplain habitat improvements in regulated and unregulated rivers such as bank stabilization, bio-engineering, grade control, and channel or floodplain reconnection |
| 33. Guidelines for making low-head and streamside infrastructure safer for recreationalists |
| 34. Guidelines for quantifying ecosystem services related to habitat rehabilitation projects |
| 35. Seasonal wetland best management practices for water conservation and salinity management |

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| 36. Guidelines for water quality monitoring plans for habitat rehabilitation projects |
| 37. Guidelines for economic methods to evaluate and quantify ecosystem services |
| Coordinate with EPA in developing geographic response plans. (Duplicate of EN-3 so not counted here) |

River Habitat Restoration (EN-5) Results

