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# Dam Removal Information Portal (DRIP)—A Map-Based Resource Linking Scientific Studies and Associated Geospatial Information about Dam Removals

Open-File Report 2016–1132

**U.S. Department of the Interior**
**U.S. Geological Survey**

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**U.S. Geological Survey**
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## Conversion Factors

Inch/Pound to International System of Units

| Multiply | By | To obtain |
|---|---|---|
| | Volume | |
| acre-foot (acre-ft) | 1,233 | cubic meter ($m^3$) |

International System of Units to Inch/Pound

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| meter (m) | 3.281 | foot (ft) |
| | Volume | |
| cubic meter ($m^3$) | 0.0008107 | acre-foot (acre-ft) |

## Abbreviations

| | |
|---|---|
| AGAP | Aquatic Gap Analysis Program |
| API | Application Programming Interface |
| CDI | Community for Data Integration |
| CSV | comma-separated values |
| DOI | digital object identifier |
| DRIP | Dam Removal Information Portal |
| EPA | U.S. Environmental Protection Agency |
| HTML | Hypertext Markup Language |
| NAIP | National Agriculture Imagery Program |
| NDRSD | National Dam Removal Science Database |
| NHDPlusV2 | National Hydrography Dataset Plus Version 2 |
| NID | National Inventory of Dams |
| NWIS | National Water Information System |
| PNAMP | Pacific Northwest Area Monitoring Partnership |
| URI | Uniform Resource Identifier |
| USGS | U.S. Geological Survey |

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By Jeffrey J. Duda[1], Daniel J. Wieferich[1], R. Sky Bristol[1], J. Ryan Bellmore[2], Vivian B. Hutchison[1], Katherine M. Vittum[1], Laura Craig[3], and Jonathan A. Warrick[1]

## Abstract

The removal of dams has recently increased over historical levels due to aging infrastructure, changing societal needs, and modern safety standards rendering some dams obsolete. Where possibilities for river restoration, or improved safety, exceed the benefits of retaining a dam, removal is more often being considered as a viable option. Yet, as this is a relatively new development in the history of river management, science is just beginning to guide our understanding of the physical and ecological implications of dam removal. Ultimately, the "lessons learned" from previous scientific studies on the outcomes dam removal could inform future scientific understanding of ecosystem outcomes, as well as aid in decision-making by stakeholders. We created a database visualization tool, the Dam Removal Information Portal (DRIP), to display map-based, interactive information about the scientific studies associated with dam removals. Serving both as a bibliographic source as well as a link to other existing databases like the National Hydrography Dataset, the derived National Dam Removal Science Database serves as the foundation for a Web-based application that synthesizes the existing scientific studies associated with dam removals. Thus, using the DRIP application, users can explore information about completed dam removal projects (for example, their location, height, and date removed), as well as discover sources and details of associated of scientific studies. As such, DRIP is intended to be a dynamic collection of scientific information related to dams that have been removed in the United States and elsewhere. This report describes the architecture and concepts of this "metaknowledge" database and the DRIP visualization tool.

[1]U.S. Geological Survey.
[2]U.S. Forest Service.
[3]American Rivers, non-profit organization.

## Introduction

For millennia, human societies have had a close association with rivers and their floodplains. During the 19th and 20th centuries, as technological advancements allowed more widespread use and manipulation of rivers, a boom in dam building occurred. Dams provided numerous societal and economic benefits, such as hydropower production, flood control, transportation, and water storage (World Commission on Dams, 2000). With this increase in dam construction, a greater appreciation of the ecological effects on rivers emerged (Petts, 1984; Magilligan and Nislow, 2005; Poff and others, 2007). The hydrological alteration of rivers changes their structure and function (Ward and Stanford, 1995; Bunn and Arthington, 2002), which can have both physical and biological effects that cascade through the system (Ligon and others, 1995; Nilsson and Berggren, 2000; Poff and Zimmerman, 2010; Ellis and Jones, 2013).

One estimate suggests that the United States has more than 2 million dams on rivers and streams (Graf, 1993). However, only a small fraction of those structures is mapped, and there is no comprehensive national database for all dams in the United States (Smith and others, 2002; Magilligan and others, 2016). A key source of information on dams in the United States is the National Inventory of Dams (NID), a congressionally mandated database maintained by the U.S. Army Corps of Engineers. The dams in this database, numbering more than 80,000, generally are those larger in size than most dams in the United States. To be included in the NID, dams must meet criteria based on height (>7.62 m) or reservoir storage area (holding more than 61,674 $m^3$ [50 acre-ft] of water), or represent a significant safety hazard in the event of a breach or catastrophic failure (U.S. Army Corps of Engineers, 2013). The database contains many fields describing different attributes of each dam, including the year the dam was built. Based on the known age of dams in the NID, more than 80 percent of dams will be more than 50 years old by 2030. Reflecting the age structure of the entire assemblage of U.S. dams, the trend of aging dams is an infrastructure issue that has partly led to an increase in dam removals over the past four decades (O'Connor and others, 2015).

The increase of dam removals in the United States and elsewhere has been influenced by aging infrastructure, changing societal needs and values, and modernizing safety standards (Stanley and Doyle, 2003). In some cases, if a dam removal provides better economics, improved safety, or possibilities for river restoration, then it may outweigh the costs of repair or rebuilding of an existing dam. Although the NID is a great resource for understanding larger dams on the landscape, it was not developed to account for removed dams. Currently (2016), the best resource for information on U.S. dam removals is a database maintained by the non-profit organization, American Rivers (http://www.americanrivers.org). This database contains information on more than 1,300 dam removals since 1912 in the United States. Records include the location, size, year built, and year removed, although this information is not present for all dams in the database. Although the costs and benefits of dam removal involve evaluating many social, economic, and infrastructure tradeoffs, research into the physical and biological outcomes of dam removal can play an important role in the decision making process.

The increasing number of dam removals has generated an increase in the number of scientific studies assessing the outcomes of dam removal. When deciding if and how to decommission dams, decision makers and stakeholders look for the "lessons learned" from these scientific studies that have examined the geomorphic, biological, and ecological effects of previous dam-removal projects. However, despite the relatively large number of dam removals, the science of measuring responses and assessing effectiveness is still a relatively young discipline. A recent working group tasked with synthesizing dam-removal science at the U.S. Geological Survey (USGS) John Wesley Powell Center for Analysis and Synthesis (http://go.usa.gov/xcyKJ) began with a literature review of dam removal science. The result of this effort was turned into a bibliographic relational database (Bellmore and others, 2015). When compared with the American Rivers database of the total known dam removals, the Bellmore and others (2015) effort identified less than 10 percent of all dam removals have empirical data-collection studies (that is, data collected before and after, or just after dam removal) associated with them (Bellmore and others, in press).

The studies that were identified cover a broad array of physical, biological, and ecological attributes; thus, for any one topic (for example, fish response, sediment dispersal), the number of dam-removal studies is an even smaller fraction of the total number of projects. Although dam removal is a relatively new means of river management, scientists continue to develop a generalized understanding and predictive models of the physical and ecological implications and outcomes of dam removal (Grant and Lewis, 2015; O'Connor and others, 2015; Magilligan and others, 2016; Bellmore and others, in press). The goal of this report is to describe an online visualization tool describing the status and trends of dam removal for the Bellmore and others (2015) database. Easy and broad access to the information in the Bellmore and others (2015) database would enable access to important data and information sources for scientists working on dam removal. Additionally, it would become an important resource for decision makers, stakeholders, and the public. The opportunity is available to create a valuable clearinghouse of scientific information about dam removal by curating the existing scientific literature on dam removal, providing a singular source of information that is routinely updated, as well as linking to other sources of geospatial information. For this initial clearinghouse version to be a sustainable, long-term tool, it needed to grow into a larger, enterprise-scale resource. This need became the basis for a funded project in 2015 through the USGS Community for Data Integration (CDI) (http://go.usa.gov/xcy8V).

## Architectural Concept

This report describes the primary products from the CDI project, including the evolving National Dam Removal Science Database (NDRSD) and the Dam Removal Information Portal (DRIP), the visualization and analysis engine built on that data system (fig. 1). The report also serves as a prototype for the new product review processes at the USGS. As a resource, DRIP is intended as a means for distributing data and software described here and made available online.

The architecture that developed through the CDI project is a set of loosely coupled components that leverage existing capabilities in the USGS ScienceBase system and introduce a number of new technologies. In order to achieve the goals of the NDRSD and to build a sustainable system, we built the components of the system into a larger research infrastructure being developed for a USGS biogeography program called the Biogeographic Information System. Although this is still under development, we describe the concepts and areas of intersection with that larger system in the following sections.

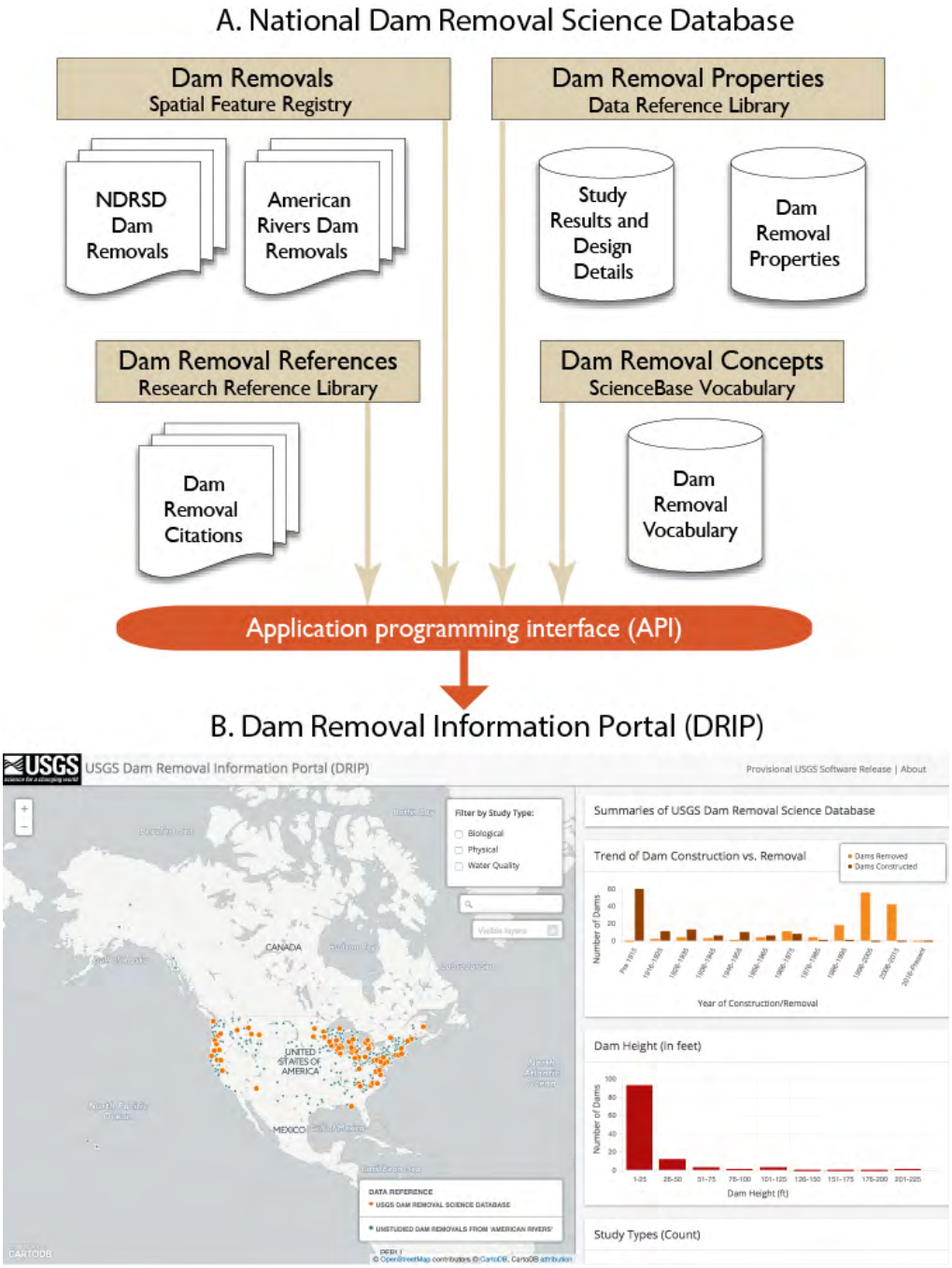


**Figure 1.** Component architecture of the National Dam Removal Science Database, showing its underlying components (A) presented at https://www.sciencebase.gov/drip (B) using an Application Programming Interface (API).

## National Dam Removal Science Database

The USGS National Dam Removal Science Database (NDRSD) is a dynamic collection of scientific information related to dams that have been removed (Wieferich, Bristol, and others, 2016). Most of these dam removals were in the United States, but information also exists from dam removals in other countries. This dynamic data system consists of several related components (table 1) and is a derivative of the USGS Dam Removal Science Database released in 2015. The NDRSD is structured as a distributed data system, consisting of several constituent registries and datasets (Wieferich, 2016a, 2016b, 2016c; Wieferich and Vittum, 2016; Wieferich, Vittum, and Craig, 2016), each with their own particular focus and structure along with different methods for ongoing maintenance and growth. The following sections describe each of the components of the NDRSD, providing an overview of the architectural strategy employed, the methods used to transform data from original sources, and some future planning and goals for some of the components.

The NDRSD is registered in ScienceBase as a logical item that describes its constituent data components. It is assigned a Digital Object Identifier (http://doi.org/10.5066/F7QR4V7Q) for citation purposes so that it can be referenced and used by others for other purposes. From a data release standpoint in the USGS, the NDRSD represents a new type of database entity—a distributed data system with diverse constituent parts with their own structures and management methods.

**Table 1.** Information sources used for the dam-removal information in the National Dam Removal Science Database.

[**Source:** Four different versions of the NID were used for this task. The NID was not set up to store information about dam removals, but when dams are removed they are often removed from the NID. Using multiple versions of the NID allowed us to identify some removed dams. **Abbreviations:** AGAP, Aquatic Gap Analysis Program; NHDPlusV2, National Hydrography Dataset Plus Version 2; NID, National Inventory of Dams; NWIS, National Water Information System; USGS, U.S. Geological Survey]

| Dataset | Contribution | Details | Source |
|---|---|---|---|
| USGS Dam Removal Science Database | Primary | Summaries of documented dam-removal science, dam characteristics, dam-removal date. | http://doi.org/10.5066/F7K935KT, |
| American Rivers dam removal database | Primary | Comprehensive list of U.S. dam removals, with coordinates, date of removal, and dam height when available. | http://www.americanrivers.org, |
| NHDPlusV2 | Supporting | Linkage to hydrologic information from NHDPlus, in addition to other physical and biological data referenced to NHDPlus (for example, NWIS, AGAP, species distribution models). | Ftp://ftp.horizon-systems.com/HNDplus/NHDPlusV21/Data. |
| NID[1] | Supporting | Information about removed dams (for example, coordinates, size, reservoir storage). | http://nid.usace.army.mil/cm_apex/f?p=838:12. |

## Dam Removals

The initial set of dam removals comes from two contributing datasets: (1) the USGS Dam Removal Science Database of Bellmore and others (2015) and (2) the American Rivers Dam Removal Database. Both sources are joined in a new capability being developed in ScienceBase called the Spatial Feature Registry—a comprehensive collection of basic information on spatial features of interest to science. Each dam is registered in the Spatial Feature Registry where it is provided a persistent Universal Resource Identifier (URI) used as a key in other parts of the data system to enable consistent reference to information about the dam and its removal circumstances. This could include references to scientific studies on a particular dam, or the particular stream segment associated with the location of a dam in the USGS National Hydrography Database Plus Version 2 (NHDPlusV2). In this way, items in the Spatial Feature Registry allow a logical model to be developed where information from multiple sources is tied together in a usable and high-quality geospatial database divided into subsets for removed dams and visualized in DRIP and other portals (fig. 1).

Because we were gathering information from multiple sources, we set out to verify the spatial location of each dam removal. In some cases, different coordinate systems were used for the spatial location, whereas in other cases precise dam location information was absent. Several steps were taken to verify the spatial location of each removed dam. When spatial information was missing altogether, or if it was only accurate to a given river or watershed, we searched both archival aerial imagery (National Agriculture Imagery Program [NAIP] and Google Earth™) and the literature to identify the location of the dam. If possible, we examined imagery from before and after dam removal in this step.

Concurrently with spatial verification, each removed dam was linked to the NHDPlusV2 using linear referencing (Environmental Systems Research Institute, 2003; Simley and Doumbouya, 2012). This helped resolve the accuracy about the dam spatial coordinates, as well as offering the potential for additional functionality when used with other geospatial tools (see, for example, Welty and others, 2015; Magilligan and others, 2016). Linking removed dams to stream segments of the NHDPlusV2 allows future developments of DRIP to access much hydrologic (for example, flow, basin area), landscape (for example, land use, land cover), and biological information (for example, fish samples, fish models) that also are referenced to the NHDPlusV2. All these additional data assets are valuable to users trying to understand and study previous and planned removals.

Supplemental sources also were used to supply missing information. The NID was used in a supporting role to provide information on location, size, and reservoir storage when this information was missing. Four concurrent versions of the NID (1994, 2007, 2009, and 2013) were used to search for dams that were removed from the list of dams in the NID because they were actually removed on the ground. This allowed us to cross-reference removed dams to their original NID identification codes, as well as to supply missing information about the structure and characteristics of each dam (for example, dam height) and associated reservoir (for example, reservoir area).

Each of these steps resulted in the information contained within the dam-removal items in the Spatial Feature Registry. We used a combination of identifiers, tags, description fields, and links to collect foundational information and source attribution on dam removals in the items. Each of the two types of dams (that is, those removed and studied, as well as those just removed but lacking associated studies) were expressed as logical ScienceBase items that reference a specific Application Programming Interface (API) query used to assemble them as datasets. These items are stored in the Data Reference Library, another developing aspect of ScienceBase. We will continue to refine how the ScienceBase item model is used to store this information as we experiment with different uses and queries.

### National Dam Removal Science Database Dam Removals

The core set of information in the NDRSD consists of those dam removals with associated scientific literature and government reports describing scientific monitoring and research. We began with the curated set of dam removals from the Bellmore and others (2015) database. These dam removals make up a dynamic subset from the Spatial Feature Registry identified with a DOI tied to a logical collection in ScienceBase for citation purposes (http://doi.org/10.5066/F77P8WGR). Currently (2016), these spatial feature details are accessed using the ScienceBase API by querying on the original identifier ("damAccessionNumber") assigned to the items. In the future, we will query the subset based on the direct association made between a dam-removal citation and a registered dam removal ScienceBase item such that the logical query will be, "retrieve all dam removals that have been associated with a reviewed dam removal publication."

### American Rivers Dam Removals

The American Rivers database provides a comprehensive inventory of U.S. dam removals, including some basic attributes such as location coordinates, year removed, and dam height for about 75 percent of cases. Project partners at American Rivers provided database records about the dams contained in their dam-removal database, which is the most comprehensive source of information about dam-removal projects in the United States (American Rivers, 2014). Since 1999, American Rivers has annually collected the data from various sources, including surveys of dam-removal practitioners, State and Federal agency staff, and media (for example, books, newspaper articles). Although the database may under-represent the actual number of dams that have been removed (because of incomplete historical knowledge, lack of formal tracking by State and Federal agencies, or disparities among States regarding what constitutes a dam), the American Rivers database is widely acknowledged as the most complete and up-to-date source of information on the total number of dams that have been removed in the United States. The number of dam removals that have associated scientific studies is a subset of the American Rivers dam-removal database, as about 9 percent of all dam removals had scientific products that fit the search criteria that generated the original USGS Dam Removal Science Database (Bellmore and others, in press).

Dam removals by American Rivers also can be selected from the Spatial Feature Registry using a ScienceBase API. Although they are sourced from a spreadsheet provided by American Rivers, the final records in ScienceBase have been sufficiently modified with spatial rectification, linking to the NHD, and other procedures to be considered inherent to the Spatial Feature Registry. Original American Rivers sourced dam removals are identified with a separate DOI as a logical collection in ScienceBase for citation purposes (http://doi.org/10.5066/F7CF9N6G).

## Dam-Removal References

Another important component of DRIP is a set of citations to scientific literature and report sources that contains empirical information about the outcomes of dam removal. This registry of dam-removal science citations initially was derived directly from a database developed by Bellmore and others (2015) at the USGS John Wesley Powell Center for Analysis and Synthesis for a working group synthesizing the science of dam removal. The database was generated from an extensive literature review of dam-removal studies published through December 31, 2014. Studies were located by using bibliographic search services (that is, Web of Science, Google Scholar™, and the U.S. Geological Survey Publication Warehouse) and search terms related to dam removal (for details, see Bellmore and others, in press). Once a candidate pool of citations was located, obviously irrelevant citations (for example, those mentioning beaver dams), or those generally discussing dam removal but not containing

empirical information, were identified and excluded. The remaining 179 studies on U.S. and international dam removals were read by subject-matter experts and attributes from each study were registered in a relational database. The tables in that database contained information on the bibliographic citations, the dams, study design, and the study results. Study results included the different kinds of metrics studied, selected from a list of available metrics within physical, biological, and water-quality categories.

For use in DRIP, the bibliographic information of dam-removal studies was integrated in the Research Reference Library in ScienceBase, another reference collection of resources similar in utility to the Spatial Feature Registry. The citation registry provides the following concepts:

- Persistent resource identifier, supporting items with and without DOIs, for linked scientific provenance in DRIP to properties derived from the literature such as the study design parameters;
- Links to online version of reports and articles;
- Storage location for copies of reports and manuscripts when links are not sufficient or reliable and storage is allowed under copyright; and
- Single point of reference for all citations from the dam-removal science database.

In this initial instance of the NDRSD, the references on dam removals are all contained in one logical container that was assigned a DOI for citation purposes as a constituent of the distributed data system (http://doi.org/10.5066/F73X84QZ). In the future, as we refine the data architecture of the system, we will shift to a dynamic query of registered citations, based on their provenance, as source material for identified dam removals and associated study details.

## Dam-Removal Properties and Studies

The original relational database from Bellmore and others (2015) contains curated information on the characteristics of the dams, the design of scientific monitoring or research studies, and the study results (Bellmore and others, in press). These attributes, extracted from scientific literature and reports, form the core of the data system that supports the analysis and visualization design for DRIP. A simple data structure linking properties with values and connected to their provenance is the ultimate objective for this part of the architecture. In the short term, we incorporated the data attributes into simple comma-separated text tables (CSV), but went the extra step of registering the variables as terms in a vocabulary around which additional capability can be built in the future (see section, "Dam-Removal Concepts").

The dam-removal characteristics were organized in two tables that are linked to the system through URIs from the Spatial Feature Registry and (or) the Research Reference Library. The tables are stored in in the Data Reference Library in ScienceBase items that contain the data, describe their processing, provide metadata, and are individually citable with DOIs:

- Dam Removal Properties (http://doi.org/10.5066/F7VH5KXK)—Provides additional details about the dam-removal projects and circumstances that could not currently (2016) be accommodated in the dam-removal items themselves.
- Dam Removal Study Results and Design Details (http://doi.org/10.5066/F7057D1D)—Provides details extracted from literature about the design of the dam-removal scientific projects and monitoring and research conducted as part of the projects.

### Dam-Removal Concepts

The two data tables, described in the section "Dam-Removal Properties and Studies," contain nearly 100 different attributes describing the characteristics of dams and the dam-removal projects. These concepts are the result of an intensive scientific synthesis across multiple disciplines and represent a meta-knowledge resource for understanding the science of dam removal and helping to inform societal and management decisions in the future. The concepts were first described explicitly as data attributes in the metadata for the Bellmore and others (2015) database. For the purposes of the NDRSD, the concepts and definitions from the original metadata were used to establish a vocabulary within the ScienceBase vocabulary system. This creates a dynamic resource available using persistent URLs in human- and machine-readable forms (https://www.sciencebase.gov/vocab/vocabulary/DamRemoval).

Each concept also is accessible at a unique persistent address within the vocabulary. These URIs were used as the column headers in the text files for the two major data tables of the NDRSD. This is an initial step toward a linked data architecture (Berners-Lee, 2006) that will comprise one of the next steps in this project. The current vocabulary implementation is limited in that it provides only the persistently identified concepts in a usable way along with individual code lists for specific attributes. It lacks sophistication as a more robust property registry where specific parameters of each concept would be managed in a data representation, but it provides a start for the development process described further in section, "Potential Future Directions and Additional Linkages to Other Resources."

## Dam Removal Information Portal

The Dam Removal Information Portal is a Web site (https://www.sciencebase.gov/drip) that serves information about the scientific studies associated with dam-removal projects (fig. 1). It is a visualization tool, including a map and interactive charts, of a dam-removal literature review designed and developed by a working group at the USGS John Wesley Powell Center for Analysis and Synthesis (Bellmore and others, 2015). Stored in a relational database, the literature review was focused on studies that contained empirical information about the physical, biological, and water-quality aspects of river ecosystem response to dam removal. The Bellmore and others (2015) Dam Removal Science Database was structured as a number of related tables that contained attribute information about the demographics (location, height, year built, year removed), the study design (for example, before-after, before-after-control-impact), and the metrics measured in each study.

The original Bellmore and others (2015) relational database was structured by Wieferich, Lohre, and others (2016) into a distributed data system—the National Dam Removal Science Database—described in section, "National Dam Removal Science Database." The components of that database were expressed as tables within a CartoDB instance to provide the underlying data for the visualization and analysis tools in DRIP. CartoDB is a cloud-based data system that provides an API and highly performing query features that are well suited to the initial instance of the DRIP tool.

The goal of developing DRIP was to not only provide a tool for indexing and visualizing the scientific studies associated with dam removals, but also to provide additional functionality, including linkages to other USGS cyber infrastructure and data. An additional goal, still in development, was to create a tool for automatically locating and indexing information about new scientific studies as they become available. In this way, DRIP would become a valuable resource for the scientific community studying dam removals.

## Visualization, Analysis, and Data Access Portal—Front End of the Dam Removal Information Portal (DRIP)

The DRIP application consists of three major components:

1. Source data managed for consistency of scientific provenance and traceability within ScienceBase,
2. A derivative database assembled from source data through code in a CartoDB database and map view, and
3. A web application from source code that provides the DRIP portal using the CartoDB API.

The source data, in various forms from data files to ScienceBase item collections (table 1) comprise the National Dam Removal Science Database. The other two components are described here.

The first prototype application for the DRIP concept was developed through a partnership between USGS and the GreenInfo Network along with a subcontract to AppGeo, a software development and consulting firm. A major design concept in the development of the application was the use of an "analytics panel" to aid in the exploration of the database and rapid analysis of the dynamics of dam-removal science in terms of the types of studies conducted relative to the characteristics of the dams and removal projects. This led the AppGeo developers to experiment with CartoDB, a commercial online service supporting robust, large-scale spatial analytics. The current size of the National Dam Removal Science Database and supporting data elements is well within the basic service offered by CartoDB, and the USGS team opted to maintain a derivative assembly of the data in that format for the initial release. Future iterations will examine other options over time, but the basic capability will be maintained in an online application that is able to run completely through an API connection to a backend service.

The DRIP web application at https://www.sciencebase.gov/drip/ is written in basic Hypertext Markup Language (HTML) and JavaScript using numerous open-code libraries documented in the source code. Data are provided through the CartoDB map and SQL (Structured Query Language) APIs to control the map and chart/table views, respectively. The use of CartoDB enables many aspects of the DRIP application, including the map interaction, to be managed directly through the CartoDB interface without changes to the web application source code. Changes to the source code are tracked through a project-management system (myUSGS JIRA) used by the USGS team, and source code is maintained in myUSGS Bitbucket Server. The DRIP application is deployed to USGS Web infrastructure from source code, following all necessary security scanning procedures. The DRIP front end will be updated over time as we incorporate additional data, explore new analytical and visualization features, and receive feedback from users. The DRIP application (source code and web instance) is registered as a software item in ScienceBase with a DOI for citation (http://doi.org/10.5066/F7M043HP).

## Potential Future Directions and Additional Linkages to Other Resources

The National Dam Removal Science Database and the Dam Removal Information Portal are both areas of active development. The organization of the database as a living, distributed data system provided opportunities to continue development of the research infrastructure known as the Biogeographic Information System, an area of active development within the USGS Core Science Analytics, Synthesis and Libraries Program. This report serves as a vehicle to obtain initial critical review of the concepts and architecture and the formal release of the data and software developed to date. Potential future work includes refining the data architecture to a more robust linked open data structure, developing methods for ongoing updates to the NDRSD assisted by text and data-mining techniques, and establishing linkages to additional structured data sources that can aid in analysis.

### Linked Open Data

The database structure for the NDRSD and its central vocabulary of concepts could benefit from a more robust instantiation of linked data methods. This work would begin with a more robust implementation of the property registry to include the full set of parameters currently (2016) contained in metadata (for example, primitive data types, range of values, additional constraints). Individual concepts and groups of concepts also would be linked to logical and coded algorithms used in extracting or deriving those concepts from literature sources and structured data, including any transformations necessary to align with the target data model of the NDRSD. We would experiment with and implement linked data technologies within the ScienceBase framework to enable advanced query methods and utilities, and we would set up automated methods for distributing new data to the CartoDB platform or other future distribution and use instances.

### Knowledge Assembly Engine

The scientific synthesis and meta-analysis work conducted by the USGS Powell Center dam-removal working group provided a powerful process framework for characterizing the types of scientific studies conducted on or associated with dam-removal projects. The team of research scientists involved with discovering applicable studies and then extracting usable information from the text provides a pattern that can be used in the creation of a software algorithm-assisted process. We have begun experimentation towards this goal, in the form of a Knowledge Assembly Engine that we hope will serve to scale up the ability to extract information into the Dam Removal Science Database and into other similar structured knowledge stores. We are modeling this work on the DeepDive project at Stanford University (http://deepdive.stanford.edu) and on specific work done by Shanan Peters and colleagues on the Paleobiology Database (Peters and others, 2014), an application originating within another science domain but very similar in underlying principles to our proposed application.

### Monitoring Project and Protocol Registry

In developing the concept for a living information resource in DRIP, we also identified the potential for creating an additional resource through providing relevant links to existing research and monitoring protocols that could be applicable for future dam-removal studies. These resources, providing the details of commonly used research and monitoring protocols, currently (2016) are being collected in a number of online resources. One such example is the Pacific Northwest Area Monitoring Partnership (PNAMP; http://www.pnamp.org), an online forum that facilitates collaboration and coordination around aquatic monitoring topics. A feature of PNAMP is the hosting and storage of monitoring resources and tools for use by practitioners. Storing commonly used protocols for dam-removal monitoring could be an important resource in future versions of DRIP.

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