Acquire Sedimentation Data to Promote Reservoir Sustainability and Advance Watershed Science

Problem and Research Objectives

Maintaining and increasing reservoir storage capacity is an adaptive measure for potential climate change impacts that also supports drought resilience and contributes to island food security and stormwater reclamation efforts. However, Hawaii's reservoirs face growing scrutiny due to heightened dam safety and flood control concerns, changing water demands, and uncertain water pollution effects. As a result, over 15% of Hawaii's regulated dam structures appear to be slated for decommissioning. Many of our remaining reservoirs show signs of significant sedimentation, accompanied by a wide range of management responses.

Sediment deposition in reservoirs is an episodically continual process, and leaving issues unaddressed until problems become acute often leads to costly, rushed, and/or ineffective solutions (Randle et al., 2013). In order to promote reservoir sustainability, it is vital that we improve our understanding of reservoir capacity loss due to sedimentation. Although the National Inventory of Dams (NID) and the State of Hawaii Dam Inventory each include records for about 140 reservoirs (Figure 1), associated sedimentation information is not part of their data schemes.

In general, reservoir bathymetry has not been surveyed systematically, and the survey information that may exist is not included in the National Reservoir Sedimentation Database (RESSED), which has no entries for Hawaii. Therefore, we are collecting, organizing, and analyzing existing physical data about reservoirs located on the main Hawaiian islands in order to achieve the following suite of research objectives:

(1) Obtain design and as-built bed elevations for all Hawaii reservoirs that are listed in the NID;

(2) Obtain other reservoir design factors (drainage area sediment yield, source sediment and bed sediment bulk density, and reservoir storage capacity loss rate) for the same facilities;

(3) Obtain corresponding data from subsequent bathymetric surveys, watershed analyses, sediment sampling, and hydrologic calculations;

(4) Organize the collected information into a database that mimics the structure of RESSED;

(5) Perform a gap analysis of the database records to identify remaining data needs;

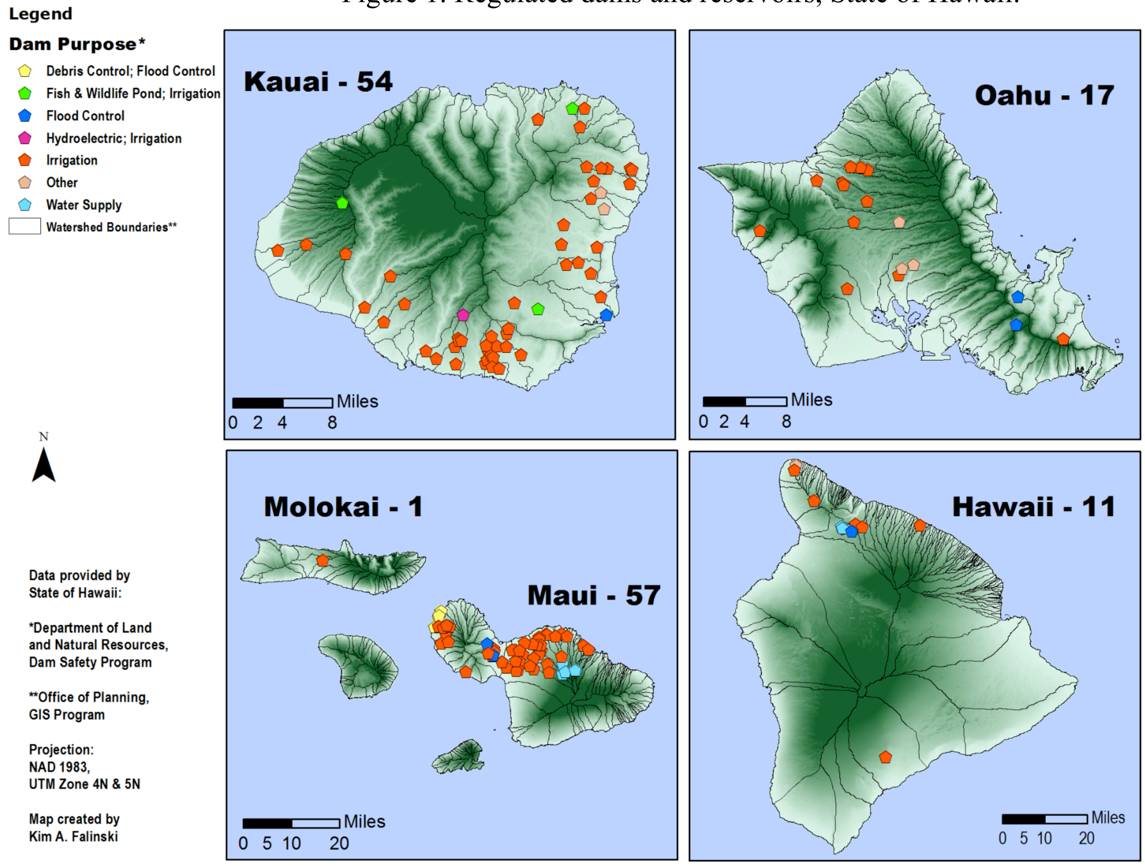
(6) Develop a sampling and analysis plan for a field and archival investigation to fill gaps in the historic record and establish new baselines for reservoir physical characteristics; and

(7) Collaborate with other investigators, agencies, and interested parties to prepare and submit follow-on proposals for implementing the sampling and analysis plan and loading completed records to RESSED.

Methodology

Approximately 140 of the largest dams and reservoirs in the Hawaiian islands are regulated under state laws that govern dam and reservoir safety (see Dam Safety Program, 2009). The state program's digital inventory is the main source of Hawaii information for the NID (Civil Works Engineering Division, 2008) and provides the most accessible, detailed, and robust starting point for obtaining, storing, and analyzing information about reservoir sedimentation. The state inventory holds 73 fields of information for each dam/reservoir record, including basic identifiers (name and id number); ownership and contact information; location (coordinates and parcel identifier); purpose; and hydrographic setting (watershed and stream).

Figure 1. Regulated dams and reservoirs, State of Hawaii.



The inventory includes other information that assists sedimentation analysis, such as dam height, reservoir size (surface area and storage volume), drainage area, and outlet and spillway design and discharge characteristics. However, storage volume values are based on design or as-built capacity to hold water and sediment; they do not reflect actual changes in water storage capacity caused by sedimentation, which is the information that RESSED is designed to hold.

The current RESSED structure includes 15 relational data tables and 375 data fields that users can manipulate to analyze sediment deposition. Most RESSED searches are linked by three data fields—reservoir identification number, survey date, and pool identification (Ackerman et al., 2009). Initial RESSED data collection and data entry was based on a standardized "Reservoir Sediment Data Summary" form developed by federal agencies (Steffan, 1996). Reservoir identification number is already provided by NID and the state inventory, and pool identification is only important for reservoirs with multiple pools, which rarely applies in Hawaii. Therefore, we are focusing on data collection to fill seven of the remaining 44 data fields found on the original standardized form:

- Field 26 (survey date)
- Volumetric survey results:

- Field 32 (storage capacity)
- Field 37 (period capacity loss)
- Field 38 (total sediment deposits to date)
- Field 41 (storage loss)

• Mass-based information:
- Field 39 (soil bulk density)
- Field 40 (tons of sediment deposited)

The data associated with these fields is not required or available in the NID and the state inventory; therefore the information must be acquired on a reservoir-by-reservoir basis from other sources. Other fields in RESSED that hold useful data for reservoir calculations and watershed analysis may be also populated as site-specific information is encountered, such as Fields 34 (period annual precipitation); 35 and 36 (water inflow by period and to date); and 42 (sediment inflow concentration).

We are searching a variety of sources to collect data on bathymetric surveys, reservoir design, and reservoir/watershed characteristics that can be used to fill these data fields, either directly or computationally. Sources include online geodatabases and data exchanges; published and unpublished technical studies, research papers, planning documents, and regulatory materials; and unpublished records held by individual dam owners, contractors, regulators, and technical/financial assistance agencies. The starting point for this effort is the reservoir-specific files maintained by the state dam safety program, supplemented by owner and agency records that we are accessing through a three-step outreach process: (1) send a letter of introduction to each of the forty main ownership entities identified in the state inventory; (2) make telephone contact; and (3) continue acquiring information accordingly, including office and site visits.

RESSED data for other states is currently accessible in several formats (Subcommittee on Sedimentation, 2013a). However, the timeframe for enabling public updating and retrieval from the forthcoming Filemaker Pro database management system is uncertain (Subcommittee on Sedimentation, 2013b). In light of this uncertainty, we chose to begin recording our data entries by adding the necessary fields to a Microsoft Excel version of the state inventory that we received from the state regulator, including fields that provide links to our project document archive. This provides a stand-alone platform for (a) gap analysis of the database records; (b) recording time and effort expended on project tasks; (c) cataloging resource materials and field methods; and (d) managing project information and developing plans and proposals for follow-up investigations. To promote interoperability with other national data systems and GIS hydrologic network applications, new RESSED data fields accommodate reach codes and measure values from the National Hydrography Dataset (NHD) that link with reservoir location; in our case, these geospatial attributes are available from the high-resolution (1:24,000 scale) Hawaii NHD (Penn and Kimura, 2009; data available for download at: ftp://nhdftp.usgs.gov/DataSets/Staged/States/FileGDB/HighResolution).

Principal Findings and Significance

The state inventory contains estimates of original reservoir storage capacity that provide a useful basis for analyzing the distribution of storage capacity among islands, owners, purposes, irrigation service areas, receiving waters, watershed contributing areas, and other significant institutional and physical characteristics. For example, on a geographic basis, each of the three smaller islands of Kauai, Oahu, and Molokai has three to five times more reservoir storage, per unit area, than Maui, which has the greatest number of reservoirs (Table 1). Hawaii island—which covers an area larger than that of all the other islands combined—has only 3% of the total statewide storage capacity. Just 10% of all reservoirs account for 2/3 of total capacity, and the state's two largest reservoirs—one on Kauai and one on Oahu—are privately owned and operated, and together account for 30% of total capacity. About 1/3 of all capacity is associated with reservoirs that are owned and operated by government agencies, primarily on Kauai (11 state/3 county) and Maui (1 state/12 county).

Table 1. Reservoir storage capacity ranked by storage per unit area.

Island	Normal Storage Capacity (acre-feet)	% of State Total	Number of Reservoirs	% of State Total	acre-feet per acre
TOTAL* **(5 main islands)**	**36,210**	<100	**133**	95	0.009
Kauai	15,553	43	52	37	0.044
Oahu	10,803	30	16	11	0.028
Molokai	4,365	12	1	1	0.026
Maui	4,347	12	54	39	0.009
Hawaii	1,242	3	10	7	<0.001

*The state inventory lacks normal storage capacity data for seven reservoirs out of 140 statewide.

However, these figures reflect optimum water storage conditions only, and do not account for decreases in storage capacity caused by reservoir sedimentation. Such changes are generally documented through recurring bathymetric surveys that quantify the rise in reservoir bed elevation over time. Our initial results indicate that resurveys are uncommon in Hawaii; reliable historic documentation of original reservoir bathymetry is sparse; and the bulk of the survey information that does exist is concentrated in the files of corporate and government offices located on Kauai and Maui.

Bed elevation is not routinely included in the data sources that we have reviewed, however knowing with certainty where the bottom of a reservoir is located is a repeated concern amongst owners and operators. In some cases, bed elevation may be roughly inferred from site topography and existing inventory data about dam height, dam base elevation, and reservoir depth (which itself must generally be derived from reservoir surface area and storage capacity). For about 60% of the reservoirs in the inventory, initial estimates of design bed elevation are available from 1970s-era investigations that include area-capacity curves, which indicate a base elevation at which storage capacity is zero (Harding-Lawson Associates, 1978). Therefore, during the coming project year we will continue compiling elevation data from these area-capacity curves, while also seeking data verification in other archival sources and assessing methods for field validation.

The availability of additional information about bed elevation and other reservoir design factors and physical characteristics varies widely. Our initial database queries, literature searches, and personal contacts indicate that it would take considerable effort (beyond the resources of the current project) to acquire reasonably complete information about each of the 140 reservoirs in the state inventory. Therefore, we are first classifying the universe of reservoirs according to levels of information availability, then targeting a subset of reservoirs in each class for focused investigation, in order to estimate the degree of effort that might be required to complete data collection for all reservoirs.

Information availability is largely a function of ownership. Public works reservoirs and those owned by larger corporations tend to have the most complete information sets. However, private owners may choose to keep their records private. Based on our initial outreach results and background research, indicates the current status of our owner-based data collection plan (Table 2).

Table 2. Reservoir ownership and data collection status.

Owner Type*	Number of Reservoirs Per Owner	Number of Owners	Level of Participation and Status of Owner Data Collection
Private-single	1	15	Four owners are participating; three with recent/pending data collection
Private-multiple	2–7	12	One owner is participating; others pending
Private-major	13 and 21	2	Pending
Public-County Agency	1–6	6	Three owners engaged; all with recent/pending data collection
Public-State Agency	2–6	4	Three owners engaged; two with recent/pending data collection
Public-Federal	1	1	Pending (field visit scheduled)
Total		40	

*Many reservoirs have multiple owners; some private owners may be corporately interlocked with others. This table is based on the first owner listed in the state inventory and does not account for corporate interlocking.

Although water storage capacity curves exist for about 60% of the regulated reservoirs, information about actual sediment delivery, trapping efficiency, accumulated volume, and release is limited. Extreme spatial and temporal variability in watershed processes complicates the calculation of sediment delivery rates, and the unique geologic and climatic setting increases the uncertainty of using established formulas from other regions. However, many owners and operators have been performing new investigations to support dam removal and other compliance with revised dam safety regulations (Hawaii Administrative Rules Chapter 13-190.1, effective February 20, 2012, http://hawaii.gov/dlnr/eng/rules), and the public records of these investigations may provide useful information. For example, from July 2010–June 2012, ten dams were at some stage of the permitting and construction process for removal, with no pending enforcement actions against dam owners (Department of Land and Natural Resources, 2011, 2012). Although these investigations typically do not include measurement of reservoir bathymetry and determination of base elevation (and changes in bed elevation over time), there are a few notable exceptions that serve as important examples for planning future work (AquaTechnex, LLC, 2009).

A more driving concern expressed by owners and operators—and one that may hold promise for future research—is to identify and employ effective and efficient sediment removal methods that meet environmental protection requirements. Our work with the reservoir community has also revealed that the financial aspect of reservoir sustainability is another critical, bottom-line concern for owners, operators, regulators, and taxpayers. In 2012, Hawaii voters rejected a proposed amendment to the state constitution that would have authorized the state to issue special purpose revenue bonds to assist dam and reservoir owners in complying with current safety standards (Engineering Division, 2012). The 2013 state legislature proposed a budget that includes line items for $9 million of reservoir safety improvements in state-owned irrigation systems and $1 million of improvements to one particular public reservoir (House of Representatives, 2013, enactment pending). A separate measure to provide $2 million for improvements to a different public reservoir stalled during the current legislative session but could be started up again next year (The Senate, 2013). In the coming project year, we will continue to record financial statistics related to reservoir sustainability, laying groundwork for future research in developing related policy, regulations, programs, and services.

Through our consultations with the state Dam Safety Program and its regulated community, we learned about the existence of at least 300–400 unregulated dams that do not have reporting requirements and represent a significant gap in watershed management information. The smaller impoundments associated with these unregulated structures may represent a manageable and compelling nexus for watershed science research to complement our analysis of the larger, more complex systems associated with regulated dams (e.g., Verstraeten and Poesen, 2001, 2002). Therefore, it may be useful to pursue follow-up projects that would inventory physical data about these smaller impoundments by replicating the approach that we are following in this project.

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