FEMA

Cost estimating dam removal: databases and drivers

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Oregon State University

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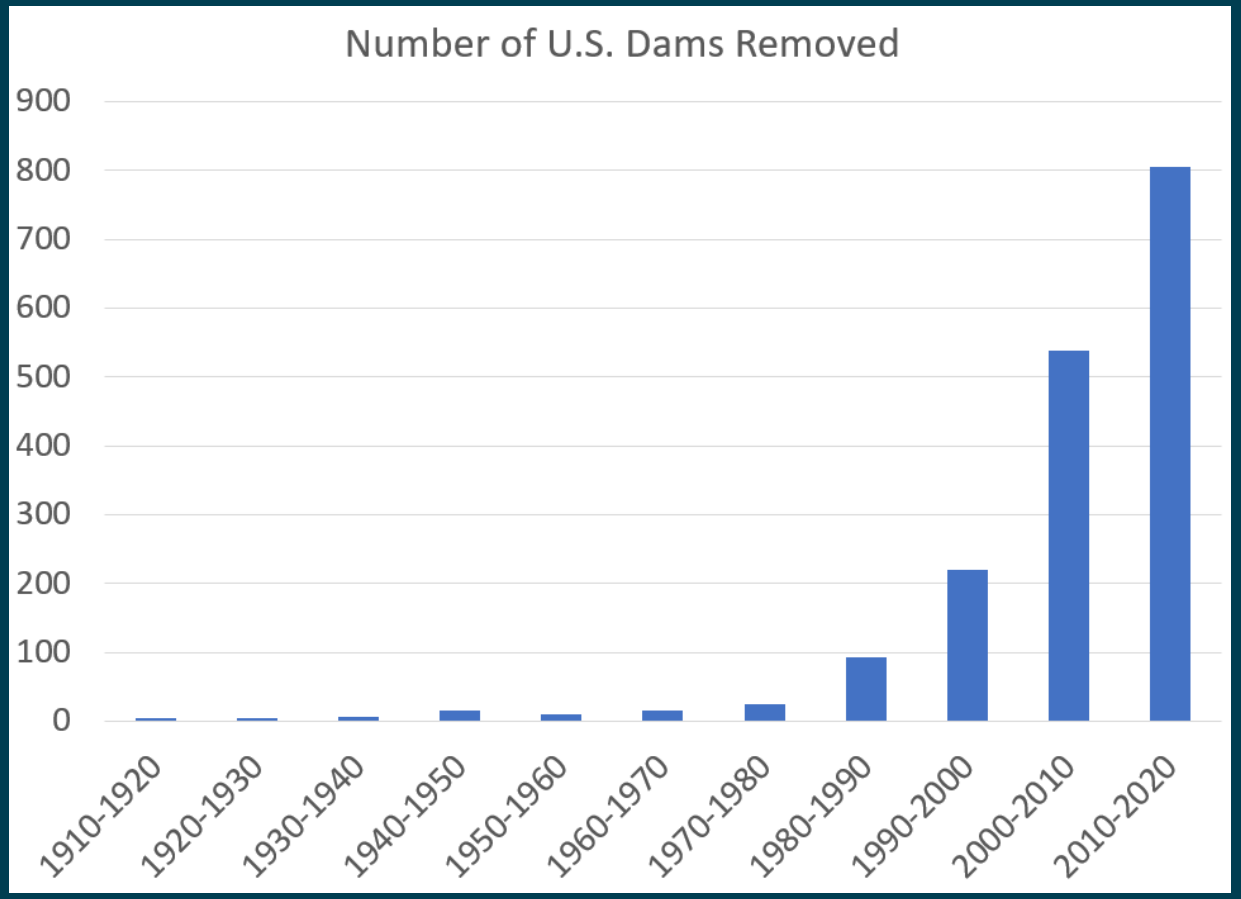
Motivation for Work: As more dams age, cost estimating data and tools are needed for dam removal planning studies



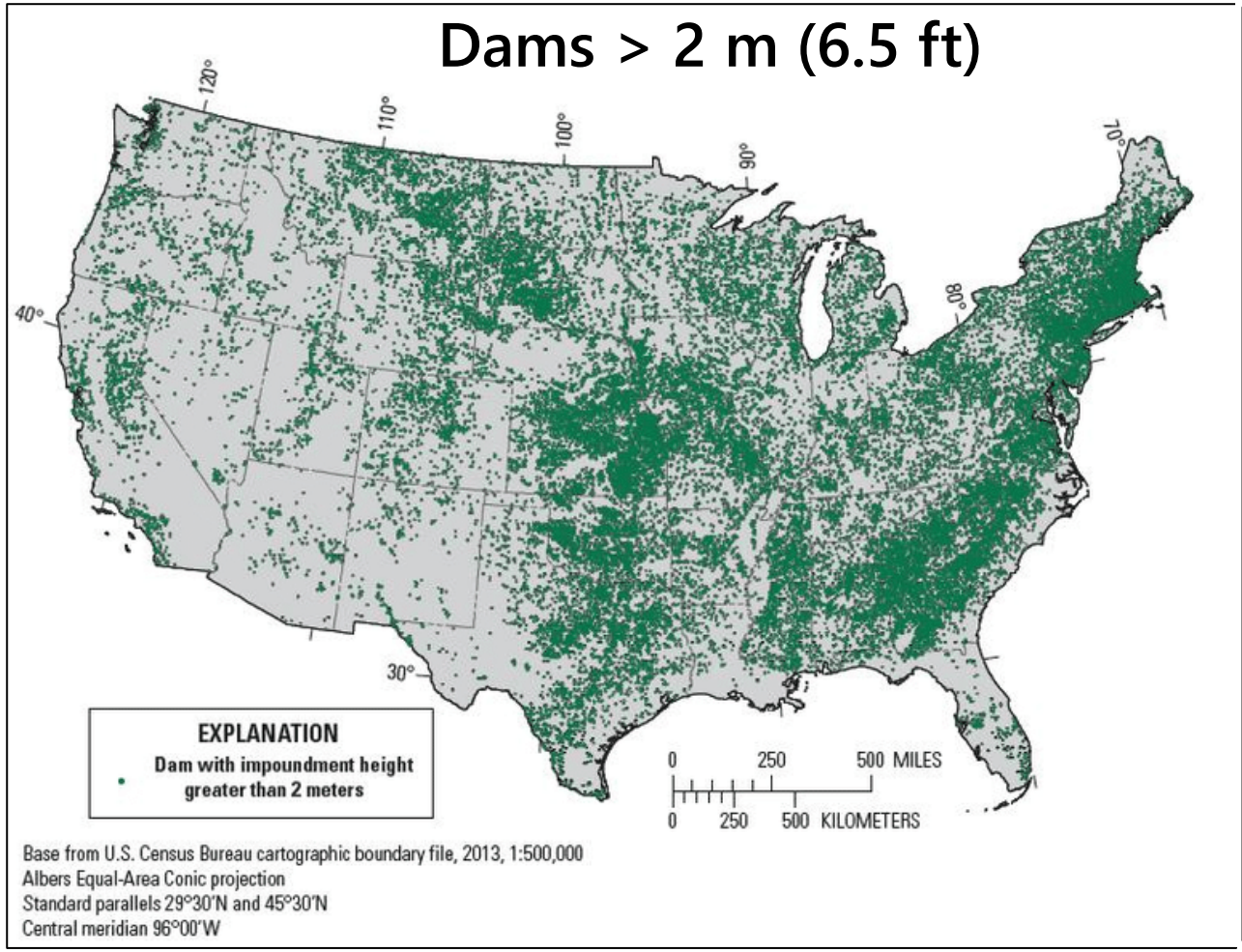
American Rivers Database Posted 2022-02-22

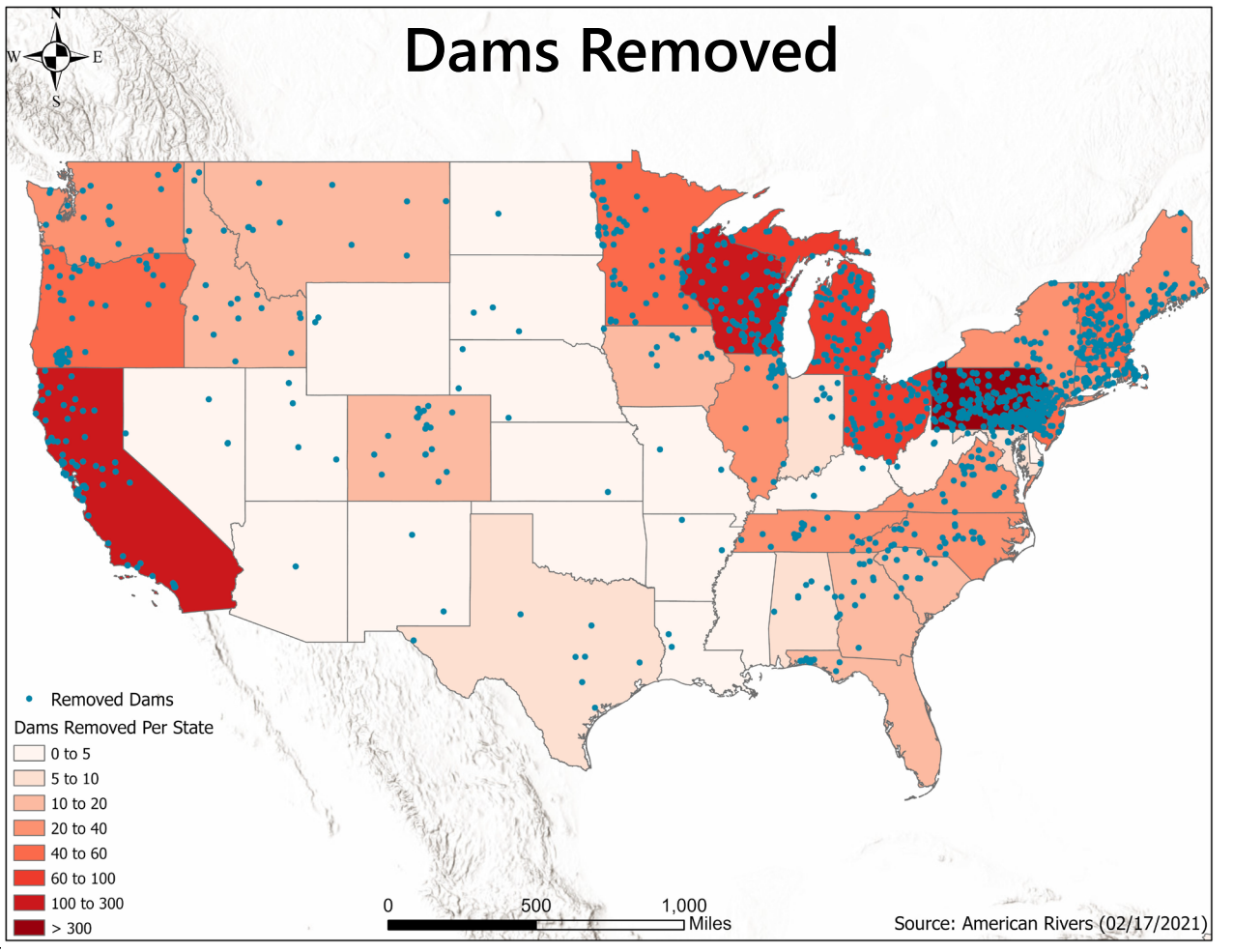
Dam Safety –alternative for large storage dams faced with expensive repairs, reduced benefits, or risk of failure

Asset Management –large reservoirs with severe sedimentation
– small diversion dams no longer needed or do not meet boater safety or fish passage requirements

River Restoration – "order of magnitude" information for dam removal grant funding and watershed planning

Despite increasing dam removal, more than 90,000 dams (and millions more small ones) remain a critical piece of U.S. infrastructure and the number far outweigh the amount removed.



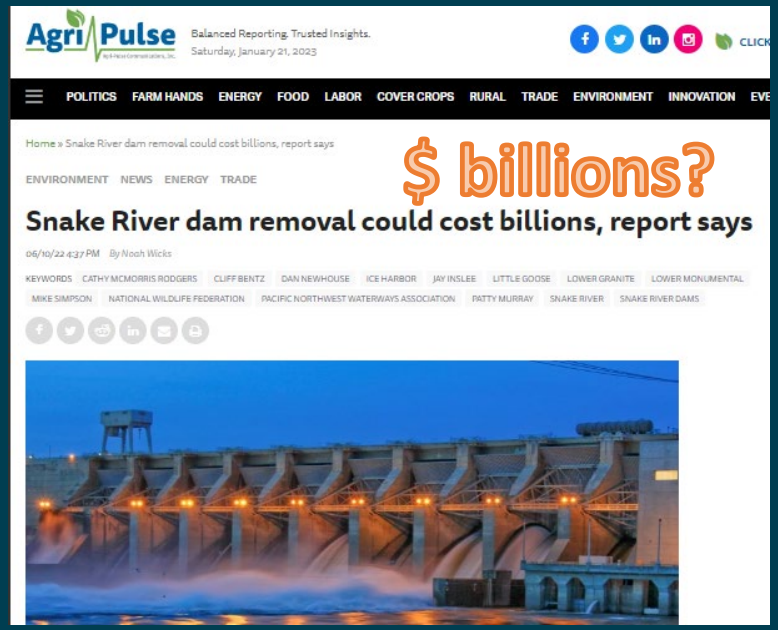


When does dam removal happen

If cost to safely maintain or repair a dam in an environmentally acceptable condition is more than cost to remove or….

the environmental benefits from removing the dam and restoring the river are greater than the benefits of maintaining the dam

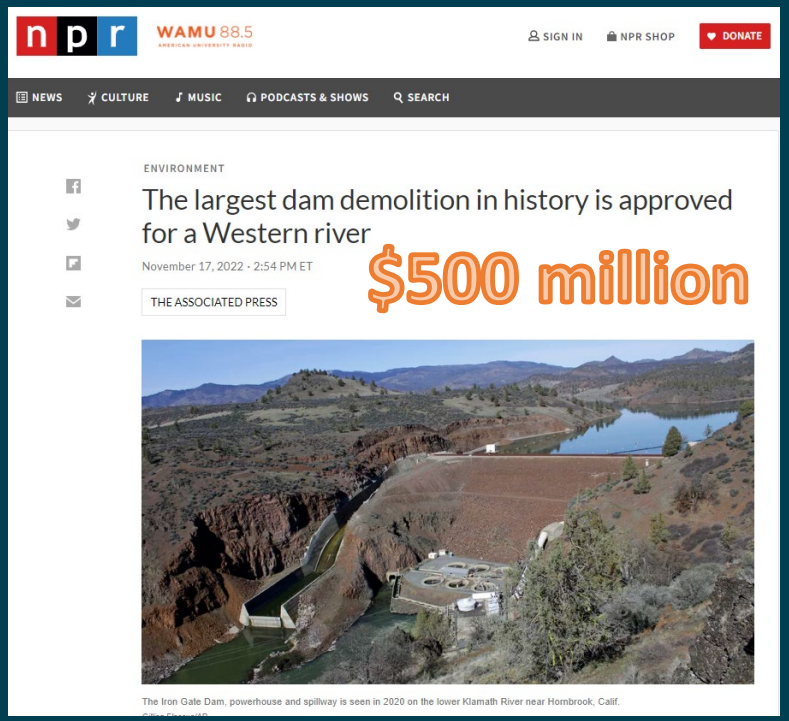
Gold Hill Dam, Oregon, USA



Excavators hammer away at the Bloede Dam shortly after its breach. Credit: Maryland Department of Natural Resources.

How much does it cost to remove a dam?

And why do some cost so much more than others?



The average cost for a dam removal project in Pennsylvania over the past three years has been ***$75,000.***

American Rivers, Association of State Dam Safety Officials Annual National Conference held in Boston, Massachusetts September 10-14, 2006

What do the dam removal data tell us

Total Costs database

- 667 cases
- Total costs only
- 32 categorical drivers (yes/no)
- GIS and web-published features
- Indexed to 2020 $

Detailed Costs database

- 15 case studies
- Costs from bid abstracts & practitioner surveys
- Detailed dam features

Construction Based Costs

- 26 case studies
- Costs from bid abstracts, schedule of values, estimates
- Detailed pay items

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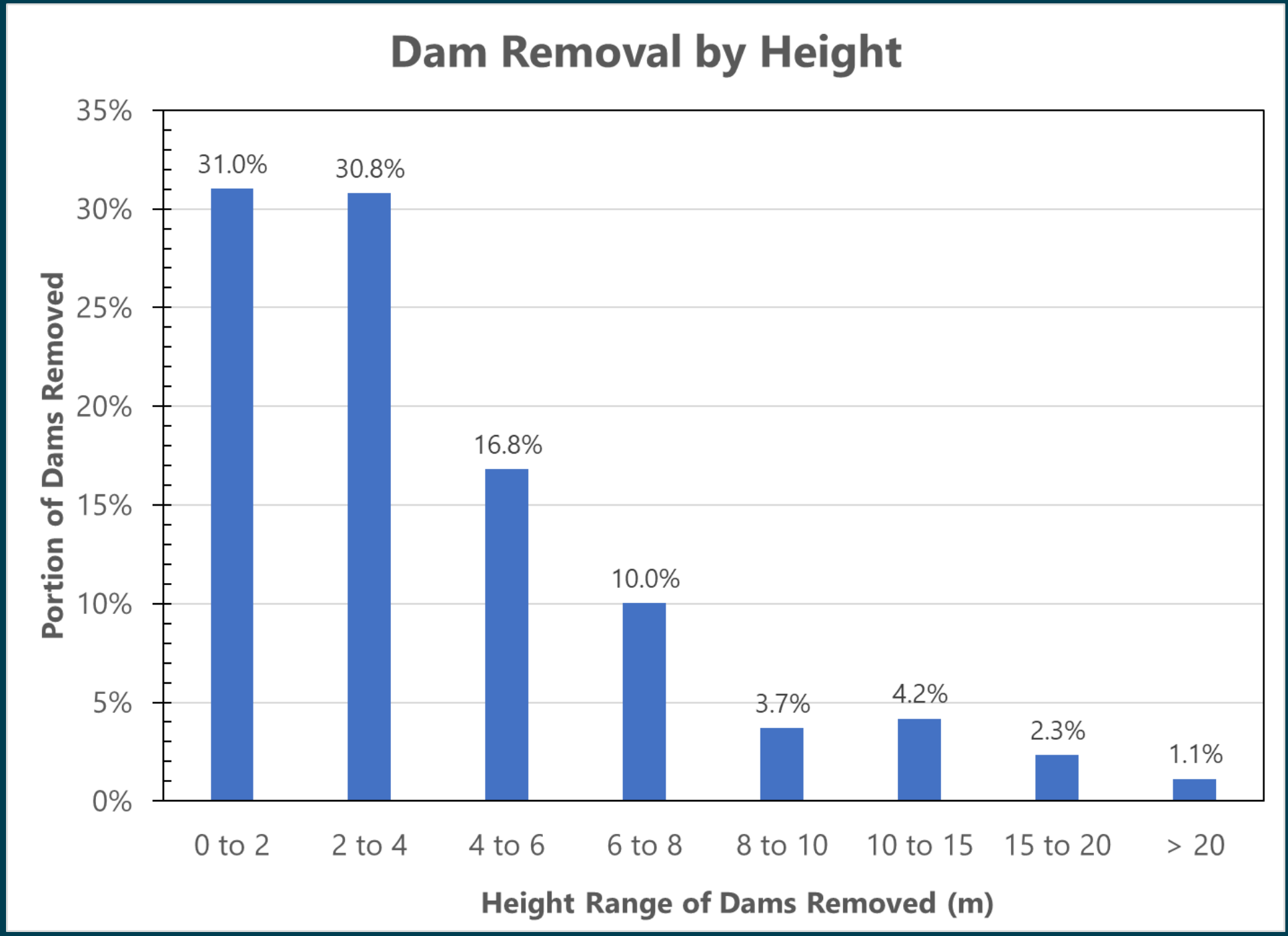
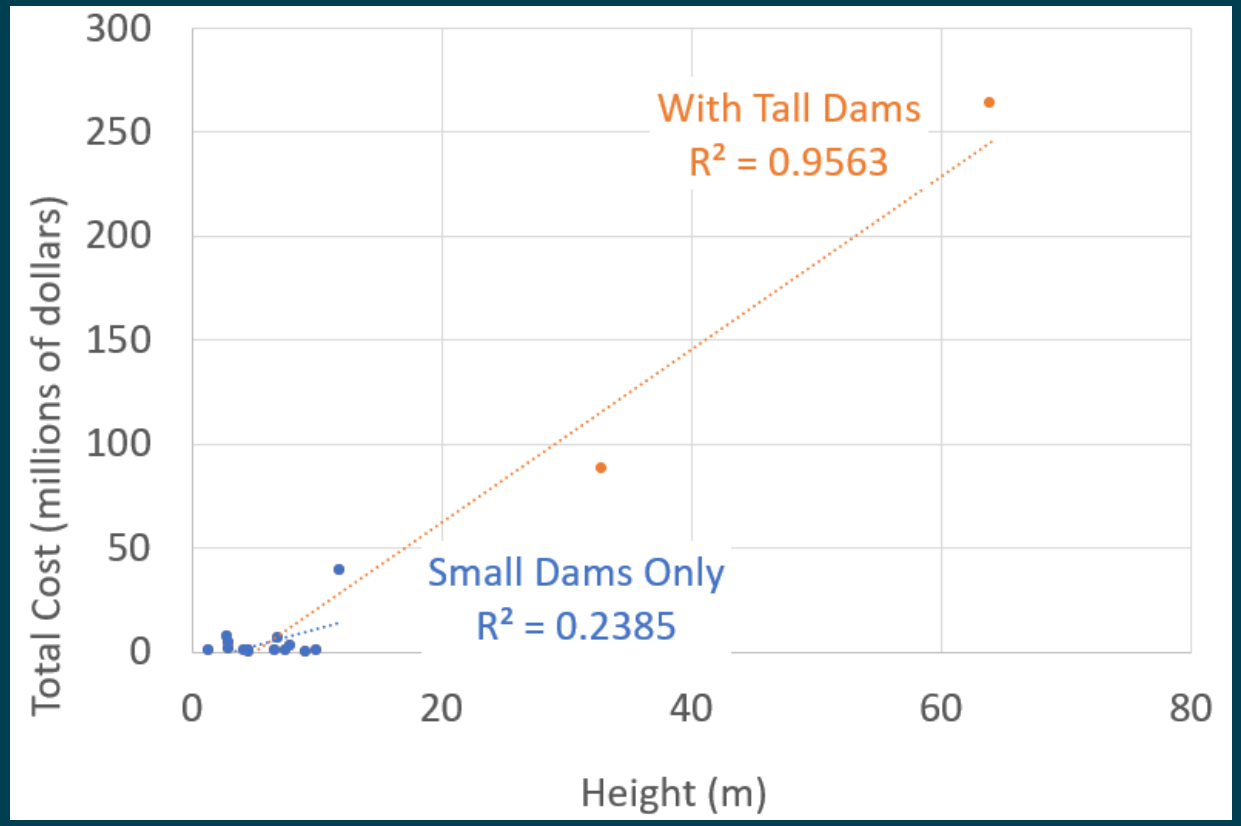
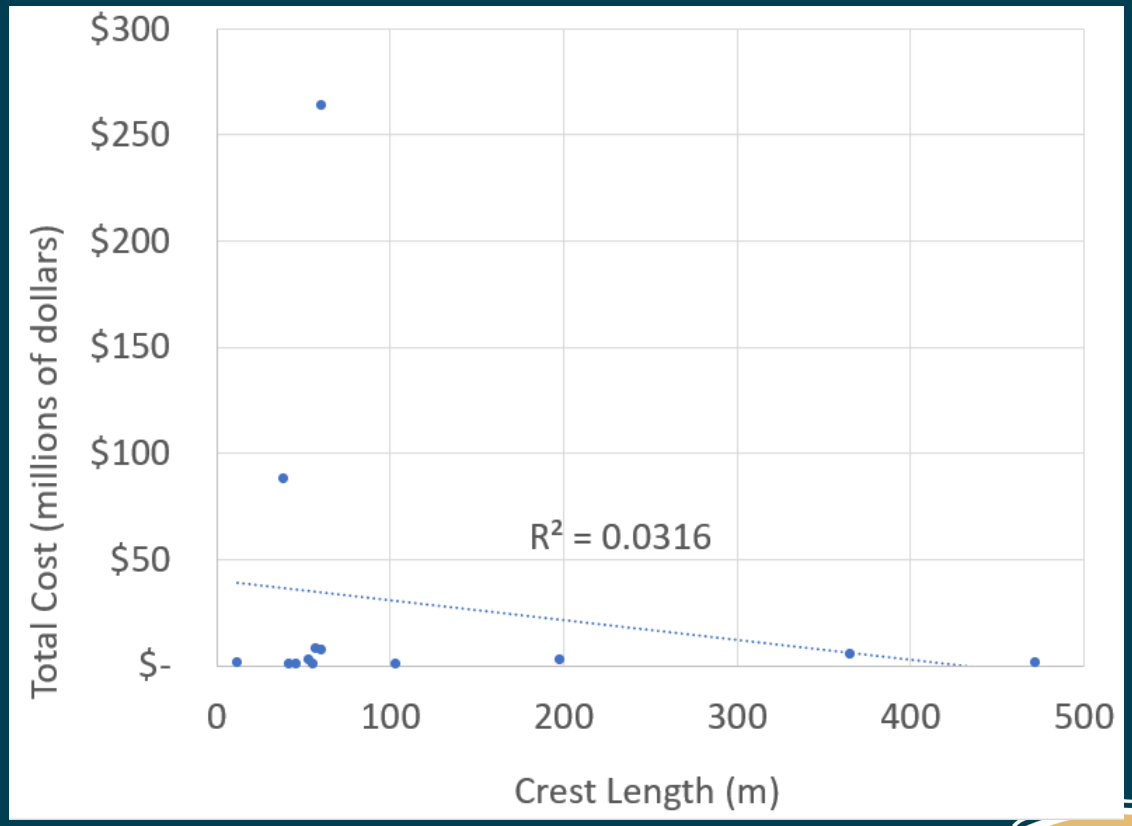
The size of dam removals vary but 92% are less than 10 m (33 ft)



Detailed Cost Database:
Is Dam Size a Good Individual Predictor?

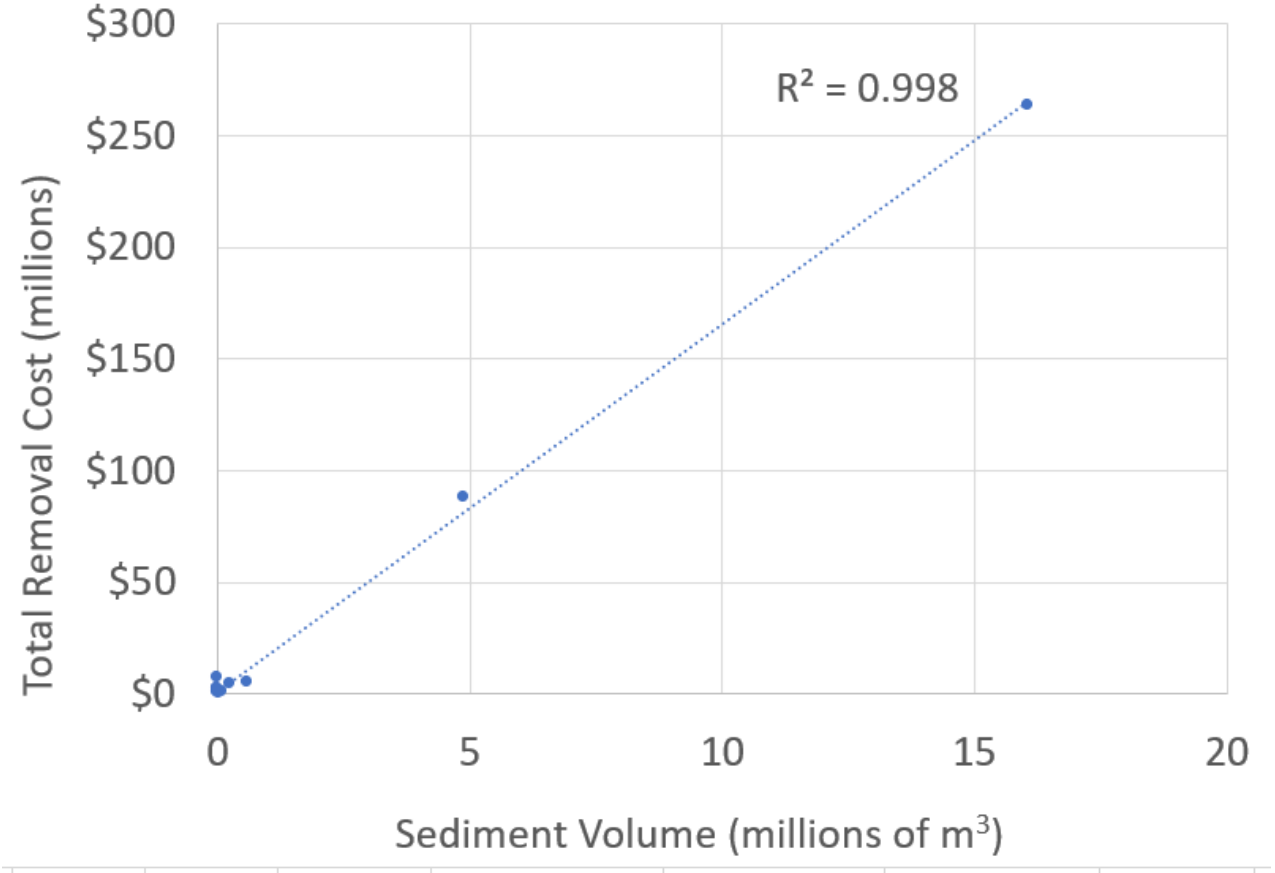




Also tried drainage area and year removed but correlation was not strong

Detailed Cost Database: Sediment volume had strong correlation

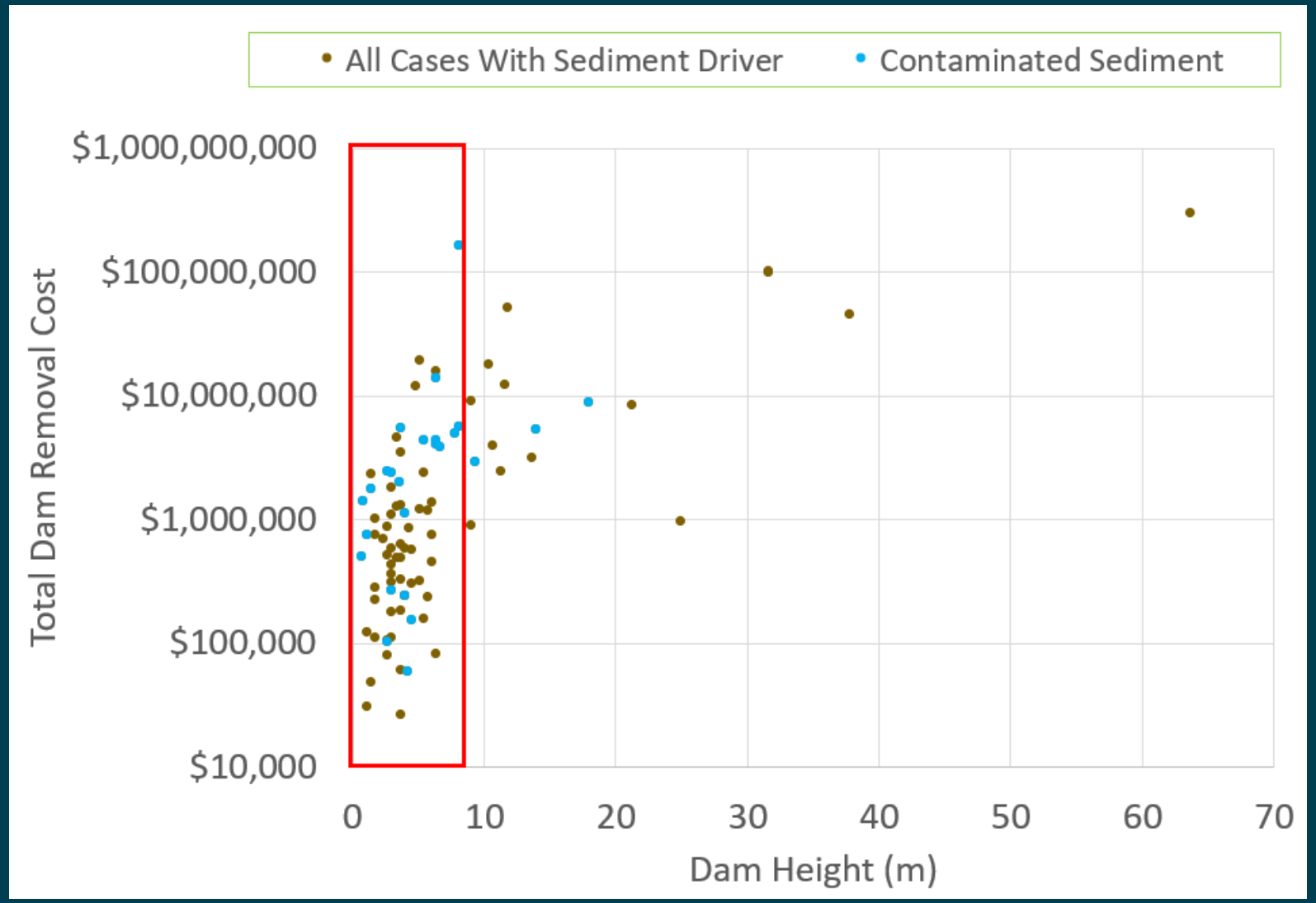
Limited data and more scatter in smaller sediment volume



Total Cost Database: Sediment Drivers

Contamination, Mechanical Removal, Pilot Channels, Stabilization, River Erosion

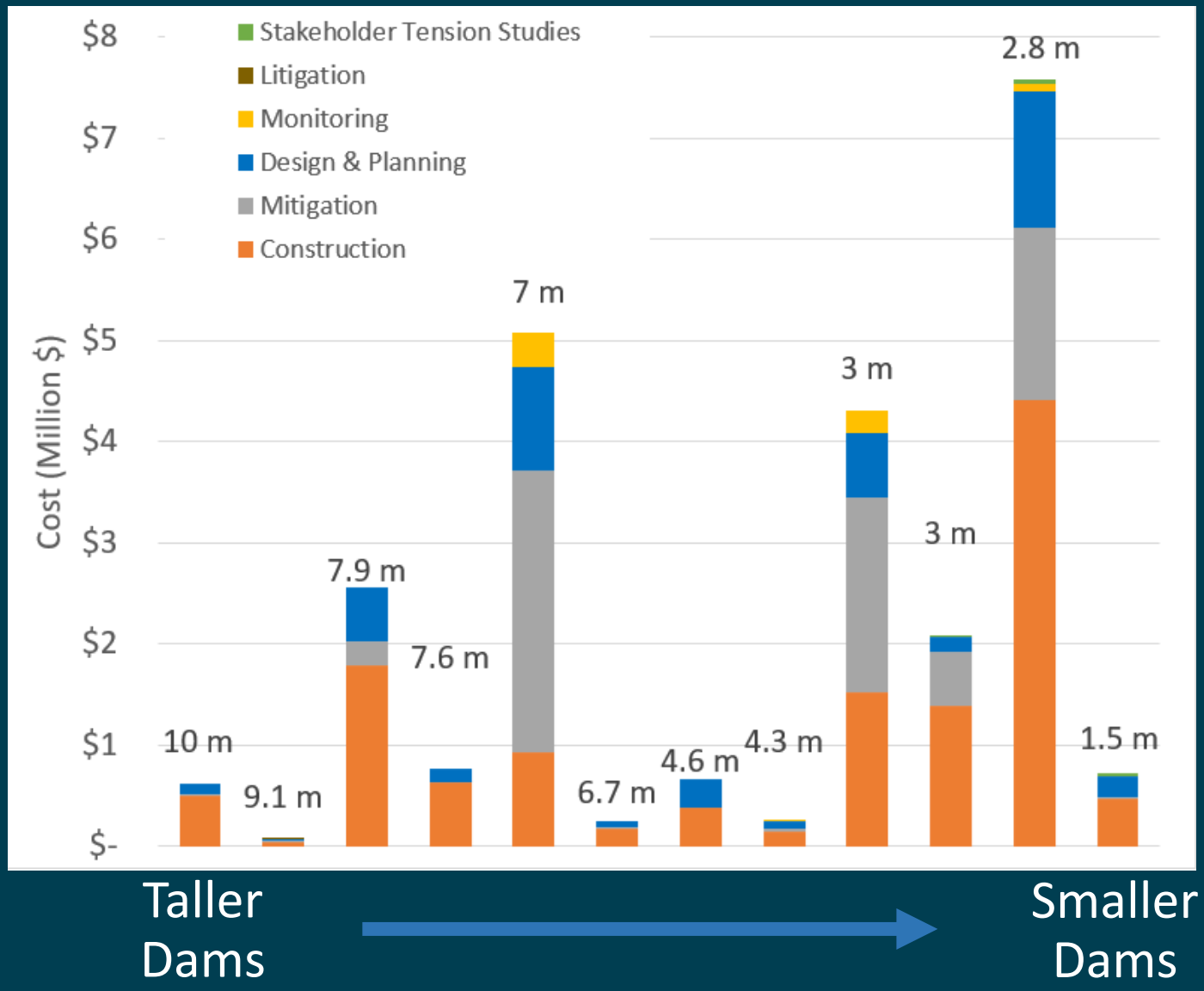
- 92 cases had sediment cost driver (14%)
- Dams 9 m (30 ft) and taller with sediment drivers cost millions to hundreds of millions
- Dams less than 9 m with sediment drivers had a wide range of costs spread out over 5 orders of magnitude



Complexity: Each Dam Has a Personality

- Gonzales and Walls (2020) found dam height, length, type (earthen or concrete) and age were statistically significant in explaining cost variance if used together, but only explained 35% of total cost
- Proposed complexity factors affect costs such as sediment handling, mitigation, and presence of other infrastructure

Detailed Cost Database: Dam Height 1.5 to 10 m

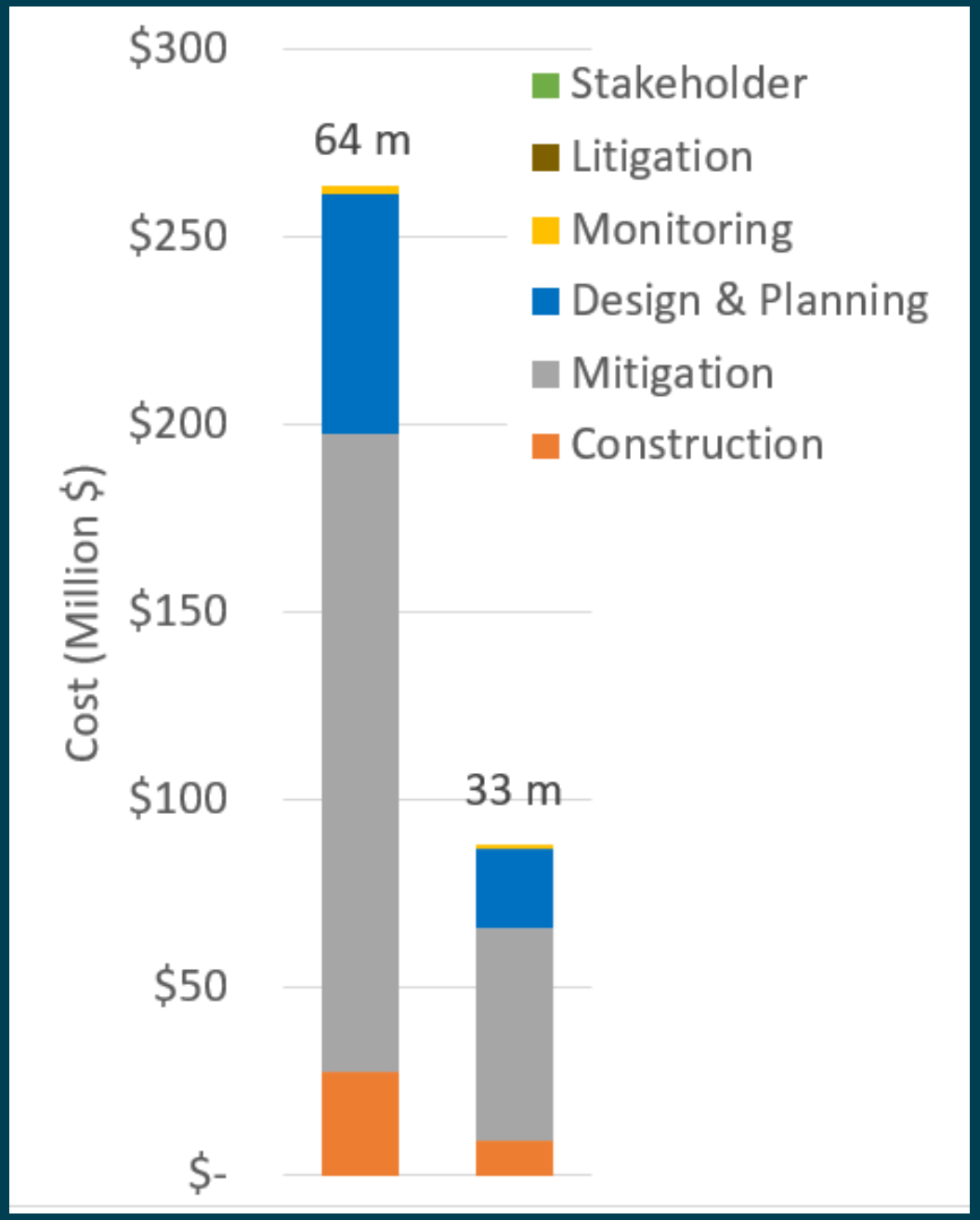


Construction, mitigation, and design accounted for over 80% of total costs

Construction:	18 to 82% of total cost
Mitigation:	0 to 55% of total cost
Design:	8 to 42% of total cost

*Litigation costs could be outside of total cost reported

*Stakeholder tension studies may be within design & planning or prior to dam removal implementation studies



Detailed Cost Database: Dam Height More Than 30 m

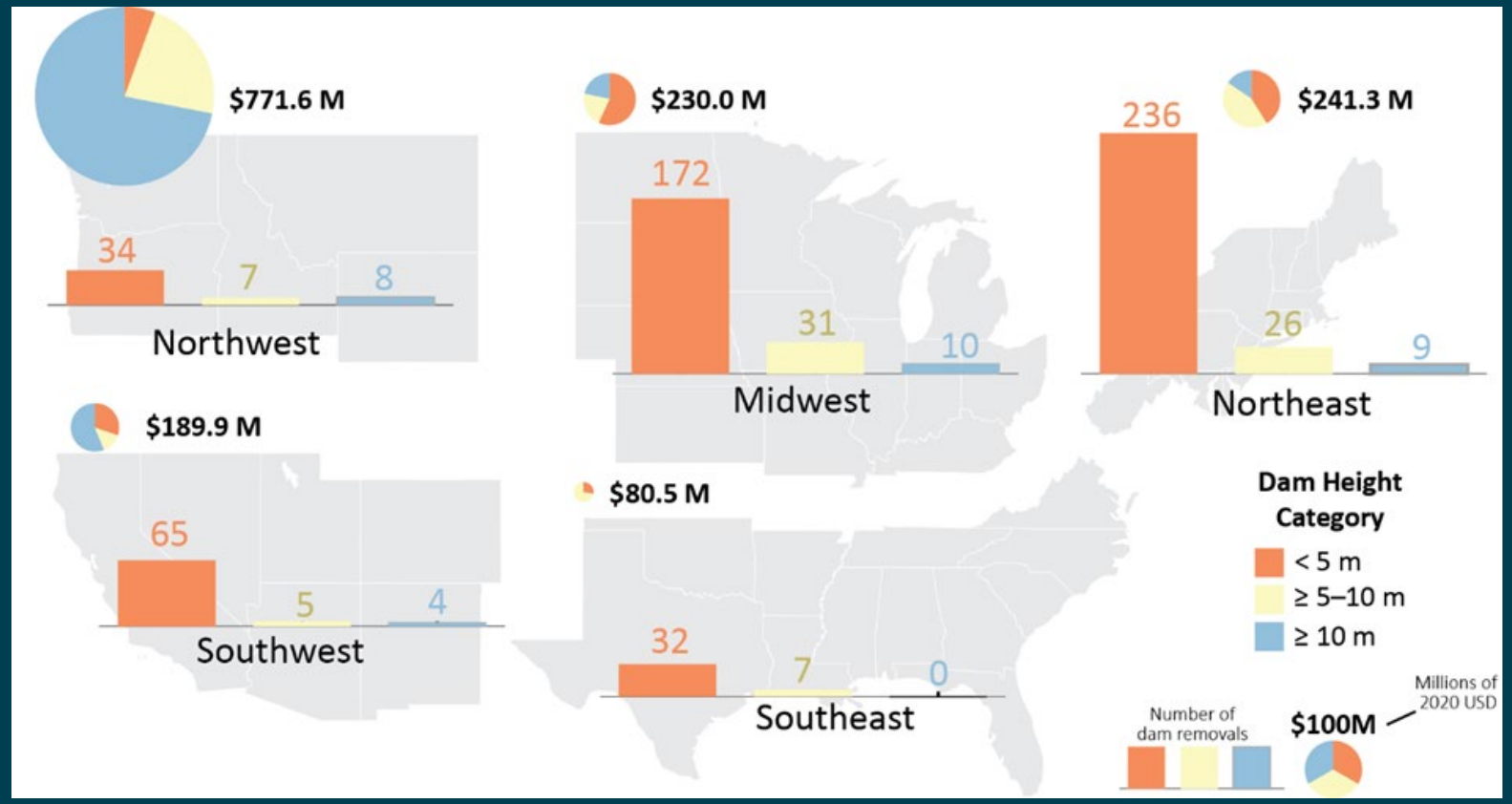
Construction, mitigation and design & planning made up 99% of total cost

Mitigation and design far exceeded construction costs

Complexity: Location location location

- Ayres & Associates (2020, unpublished, Pete Haug) proposed a complexity factor and considered geographic influence of 40 case studies
- Noted stakeholder tension studies & litigation can elevate costs
- Blumm & Erikson (2012) studied 9 dams in Pacific Northwest
  - took a range of 2 to 29 years to complete
  - affected by “dam size, FERC licensing process, community support, political leadership, and funding available”

Complexity: Location location location (2)



Total Cost database indicates dam removal could be more expensive in certain regions where total cost is higher but fewer dams have been removed

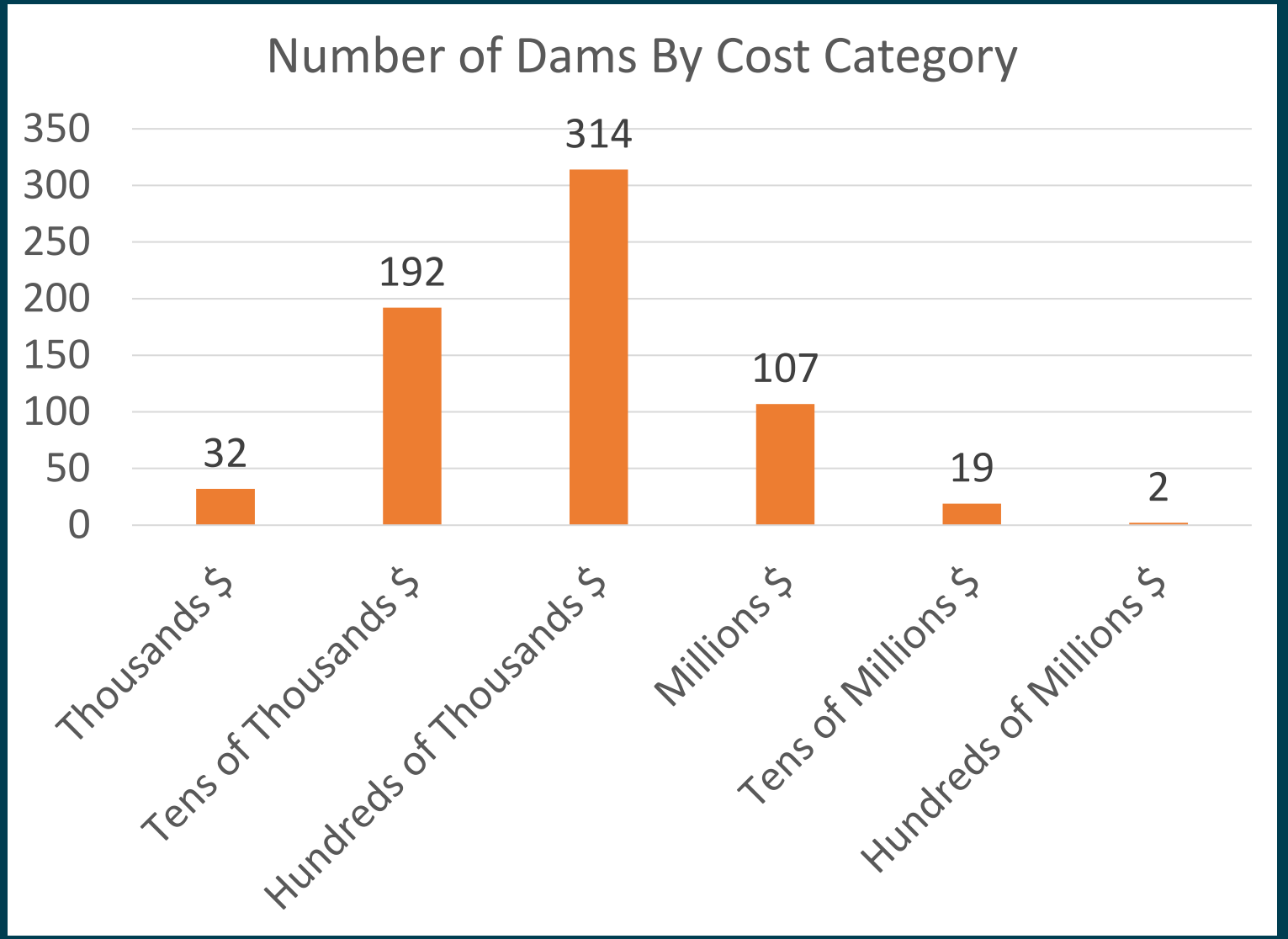
$1.5 billion investment in dam removal

Total Costs Database

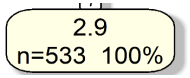
Average cost $2 to 3 million

Minimum $10,000

Maximum $200,000,000



Pruned regression tree for dam removal costs (millions 2020 $)

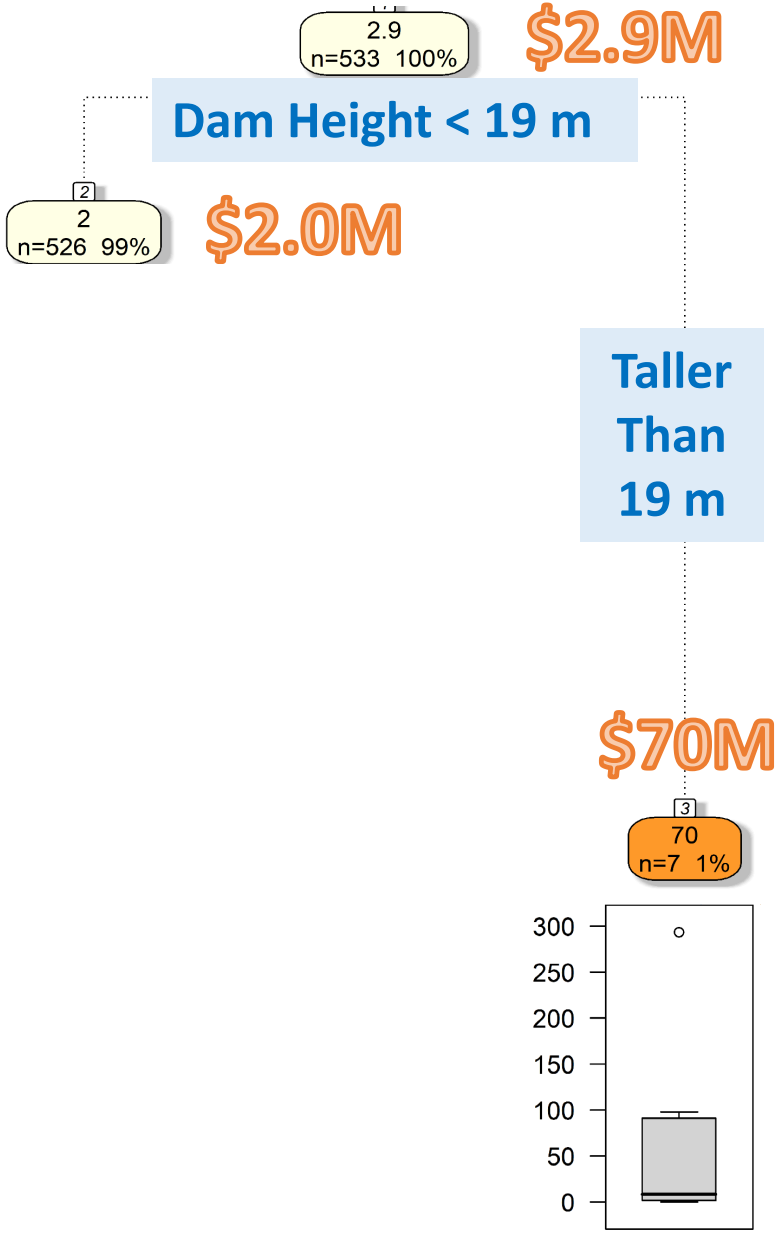


$2.9M

Using all cases, average cost is $2.9M but machine learning on the data provided some valuable insights…

Suman Jumani (ORISE Postdoctoral Fellow, USACE)

Pruned regression tree for dam removal costs (millions 2020 $)



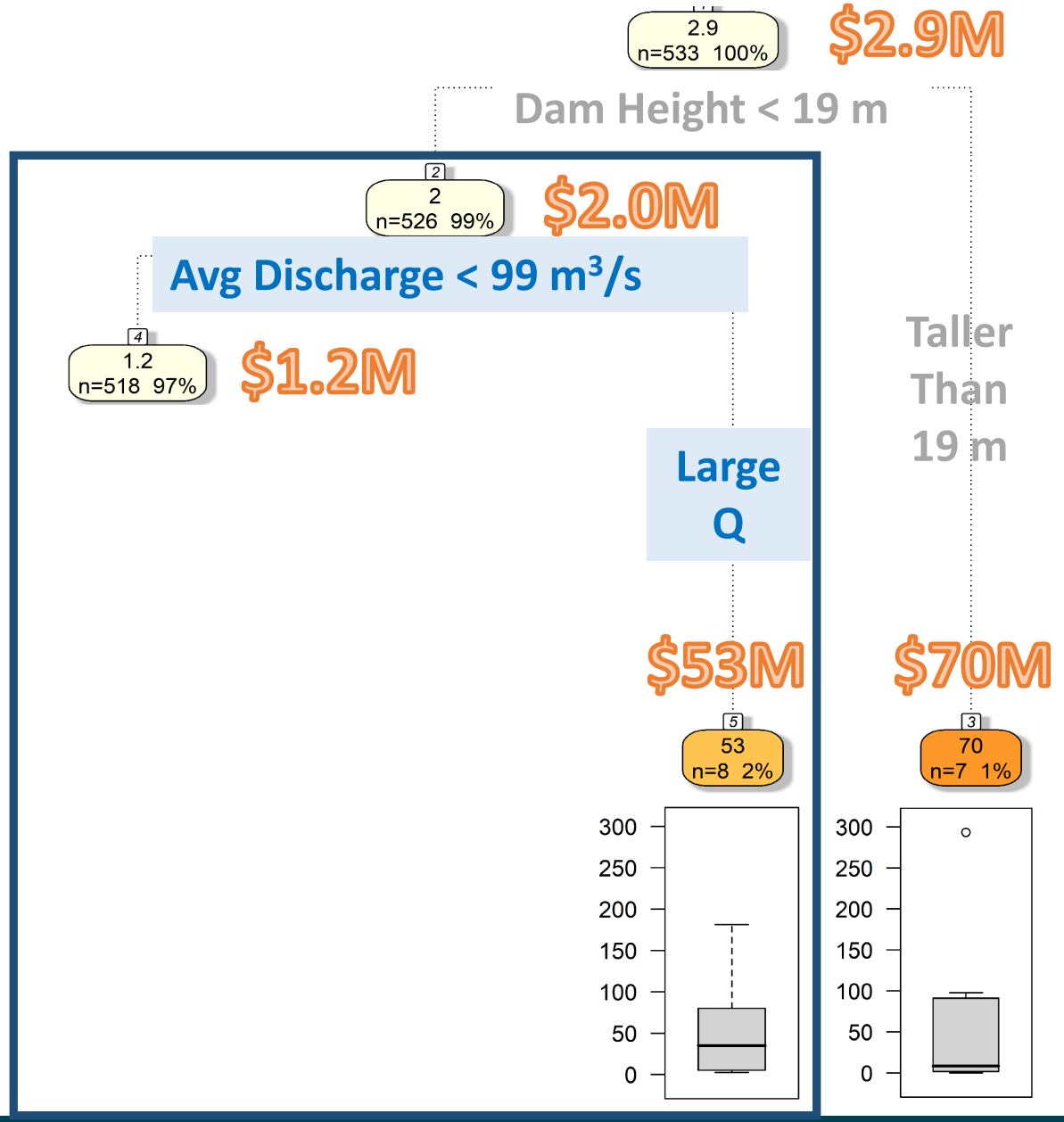
Separate out very tall dams

Most expensive dam removals: $70M

Dams ≥ 19m (62 ft) height

Suman Jumani (ORISE Postdoctoral Fellow, USACE)

Pruned regression tree for dam removal costs (millions 2020 $)



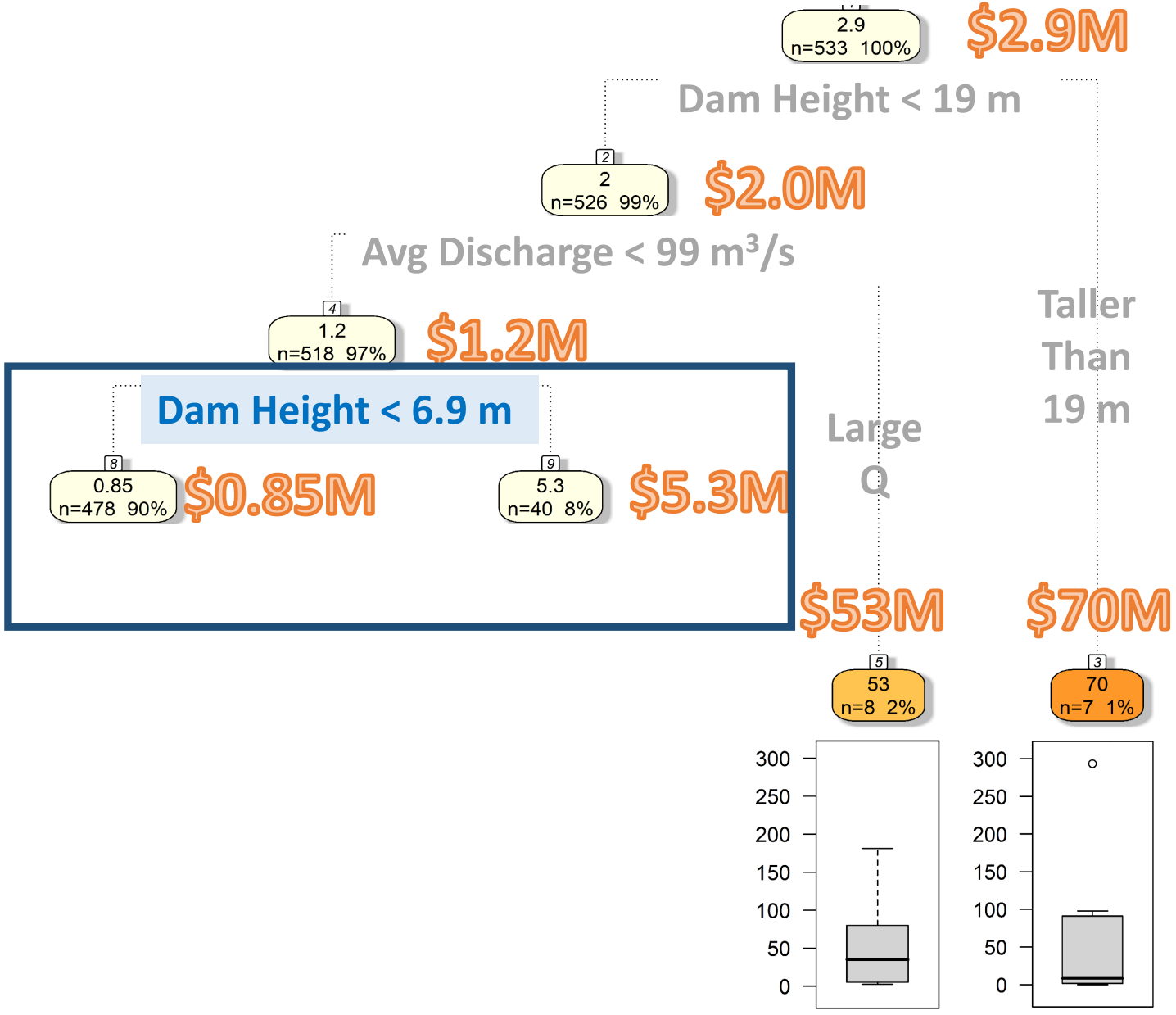
Break out dams with large average annual discharge

High costs $53M

Dams with large discharge ≥ 99 cms (3,479 cfs), but <19m (62 ft) high

Suman Jumani (ORISE Postdoctoral Fellow, USACE)

Pruned regression tree for dam removal costs (millions 2020 $)

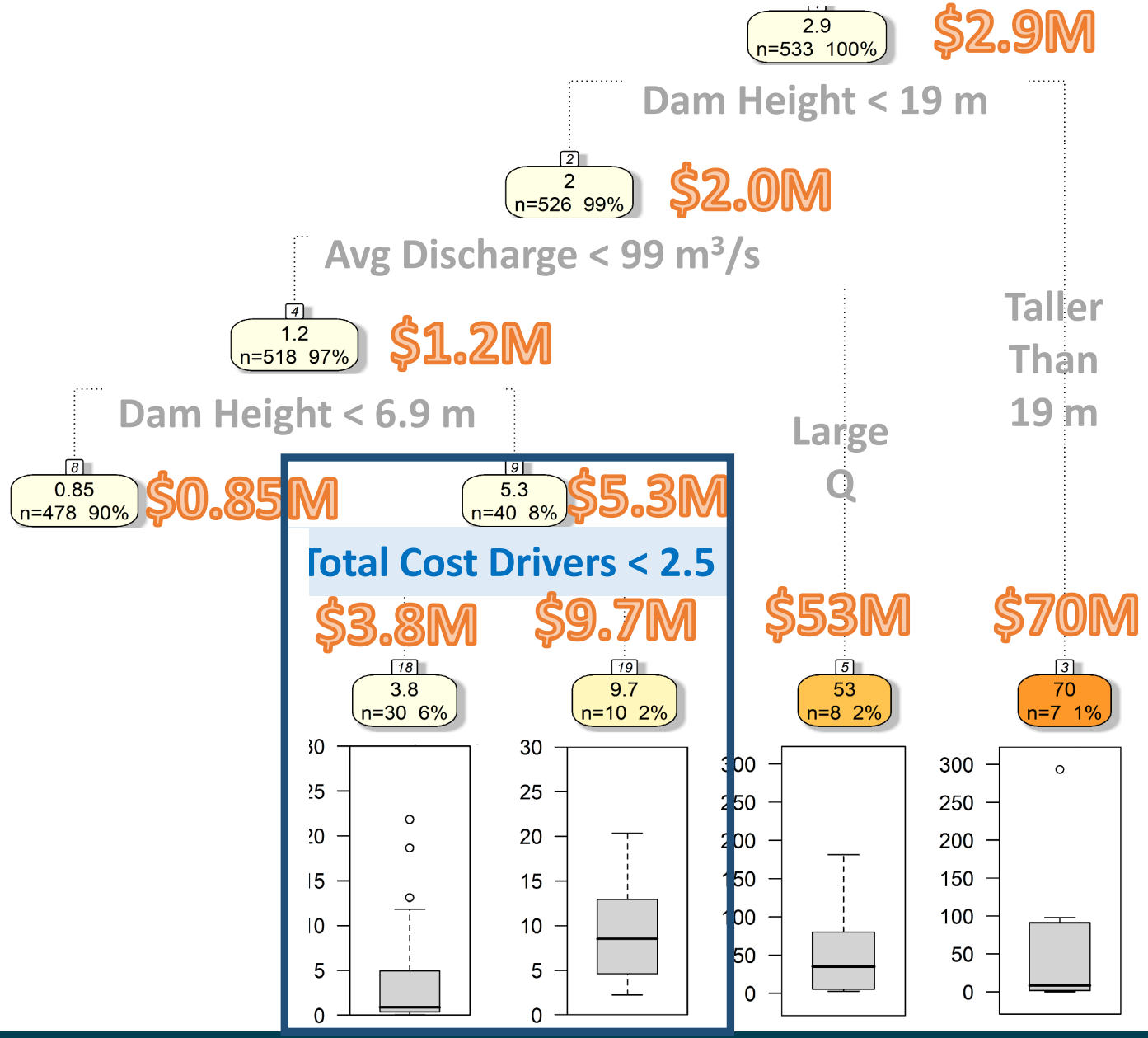


Further subdivide dams by height of 6.9 m (23 ft)

Most dams smaller than 6.9 m (23 ft) cost less than $1 million IF they don't have large discharge or significant mitigation required

Suman Jumani (ORISE Postdoctoral Fellow, USACE)

Pruned regression tree for dam removal costs (millions 2020 $)



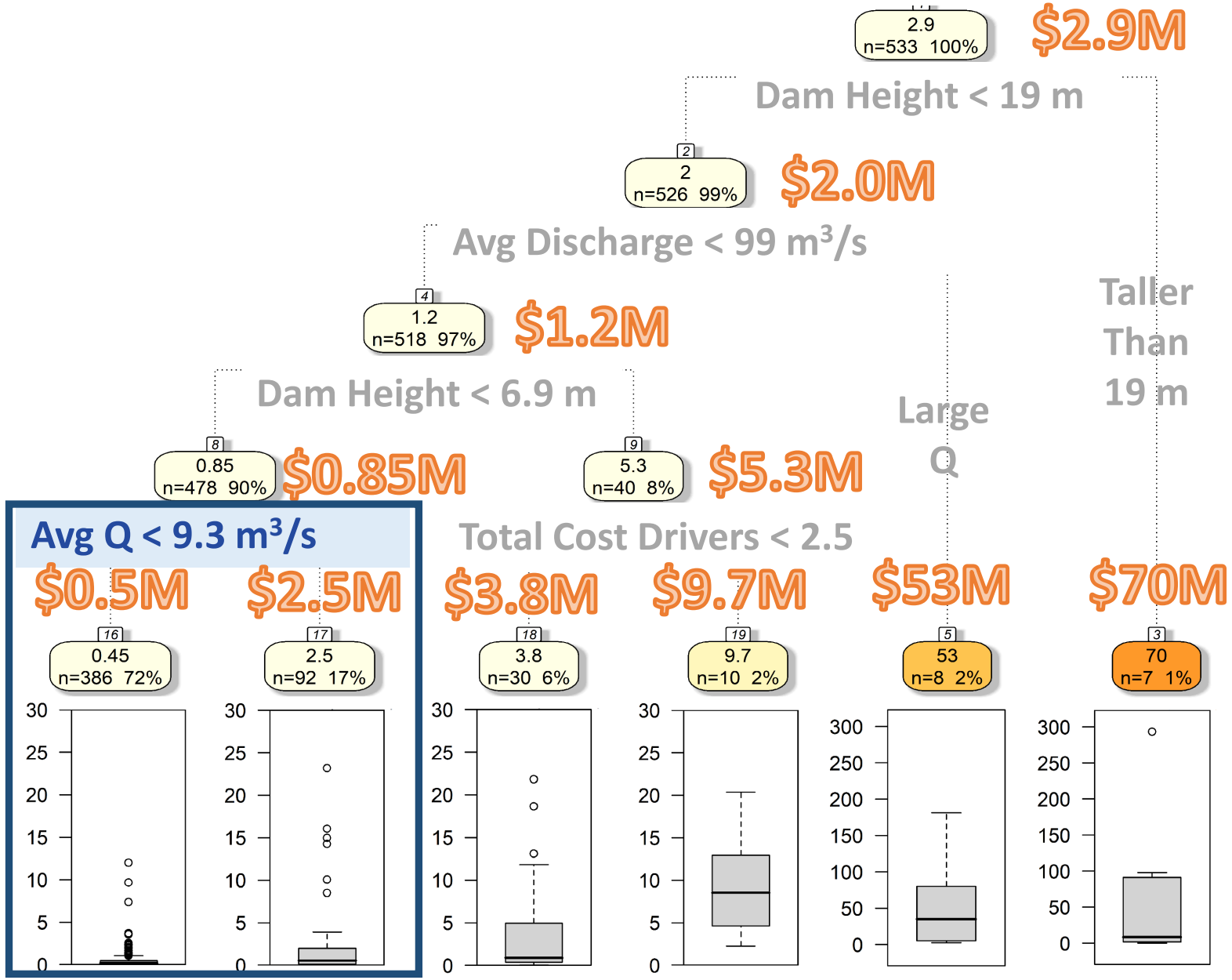
For dams between 6.9 to 19 m (23 to 62 ft) use complexity drivers to subdivide

Less complexity cuts the cost of moderately tall dam removals by more than half from $9.7M to $3.8M

Larger dams or sites on bigger rivers are all complex

Suman Jumani (ORISE Postdoctoral Fellow, USACE)

Pruned regression tree for dam removal costs (millions 2020 $)



For dams < 6.9 m (23 ft) use average annual discharge again

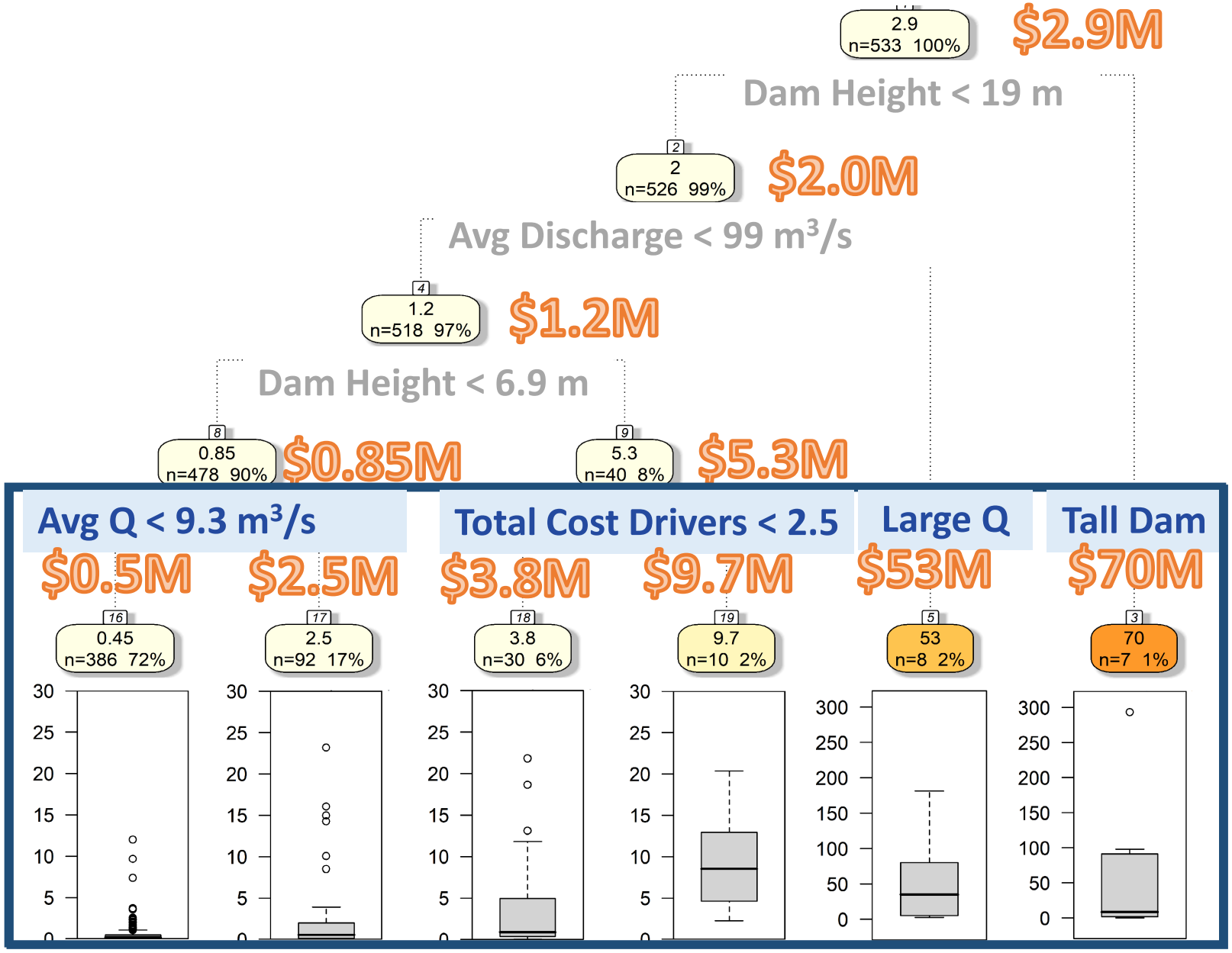
Lowest cost dam removals are less than 6.9 m (23 ft) with Q < 99 cms (3,479 cfs)

Q< 9.3 cms (329 cfs) is 1/5 cost of higher discharge

Outliers with high cost still persist

Suman Jumani (ORISE Postdoctoral Fellow, USACE)

Pruned regression tree for dam removal costs (millions 2020 $)

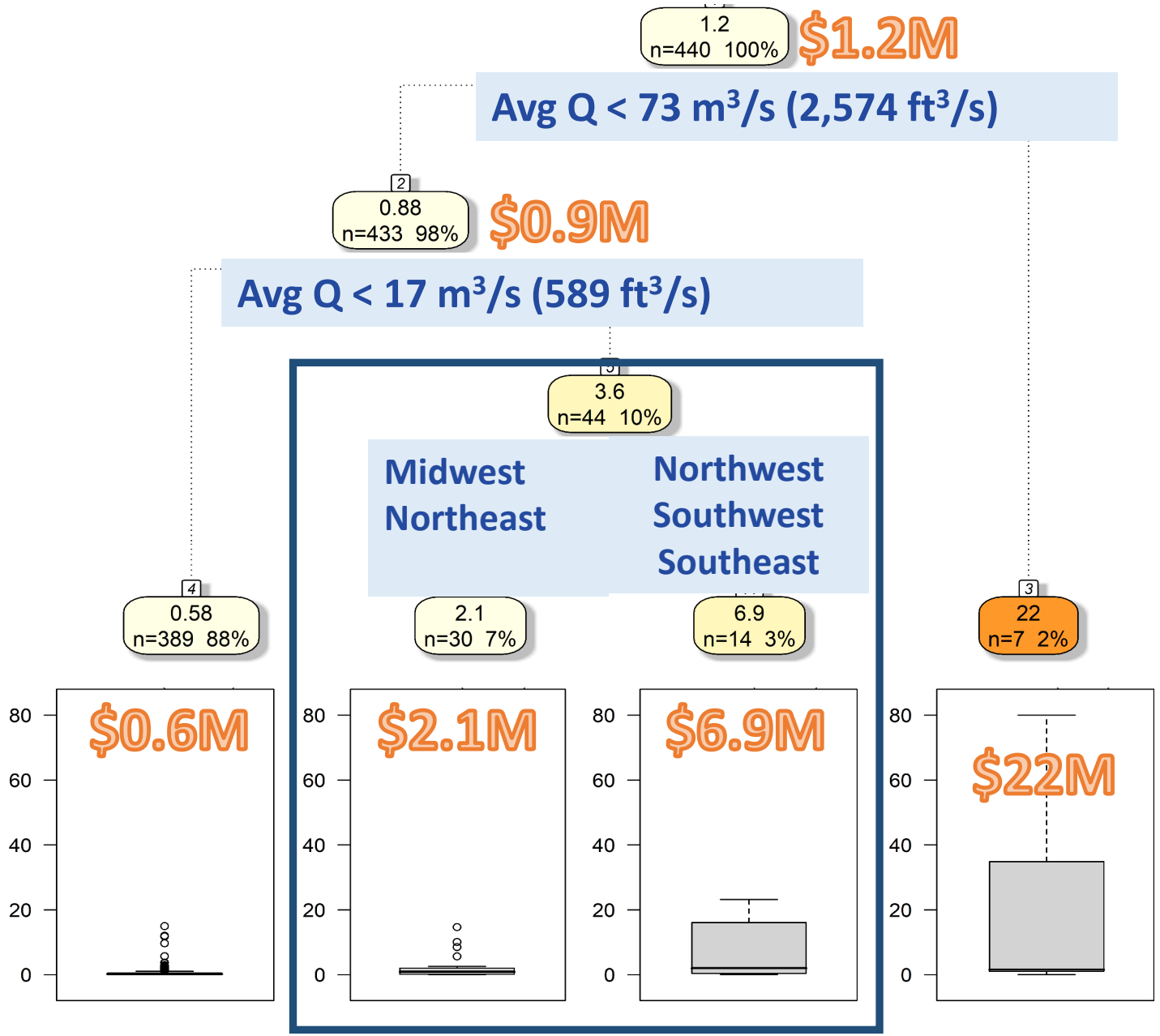


Findings

- **Under $1 Million** -> small dams & small avg annual Q
- **Millions $** -> Range of dam heights, moderate Q, complexity can shift cost up
- **Tens of Millions $** -> large avg annual discharge or tall dams

Suman Jumani (ORISE Postdoctoral Fellow, USACE)

Pruned regression tree for removal costs of dams < 6.9 m (millions 2020 $)



Using Only Dams Less then 6.9 m (23 ft)

- **Under $1 Million** -> small dams with small avg annual discharge
- **Millions $** -> small dams with moderate discharge
  - Geographic location
  - Permitting procedures, experience with prior removals, contaminants
- **Tens of Millions $** -> small dams with large avg annual discharge

Construction Lens

- Removal of Savage Rapids Dam, OR

Pay Items and Complexity

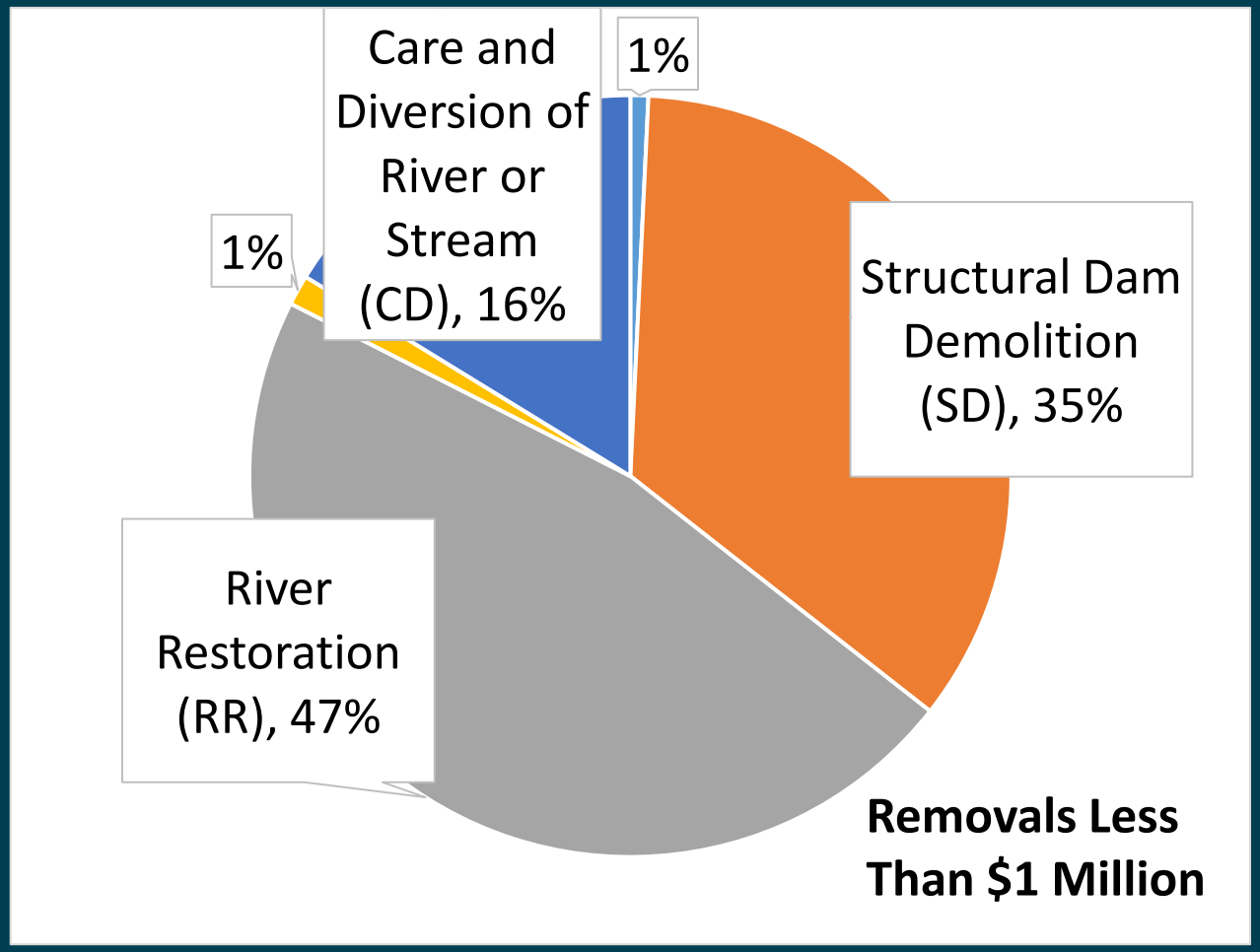
- Contractor will be paid for the work represented by the appropriate **pay items** as the work progresses and is acceptably performed.
- **Source 1: Schedule of values** represent all the pay items submitted by contractor to get paid for a past dam removal
- **Source 2: Bid abstracts** for competing estimates for a past dam removal
- **Source 3: Government & private sector estimates** represents estimates on expected pay items for a potential dam removal

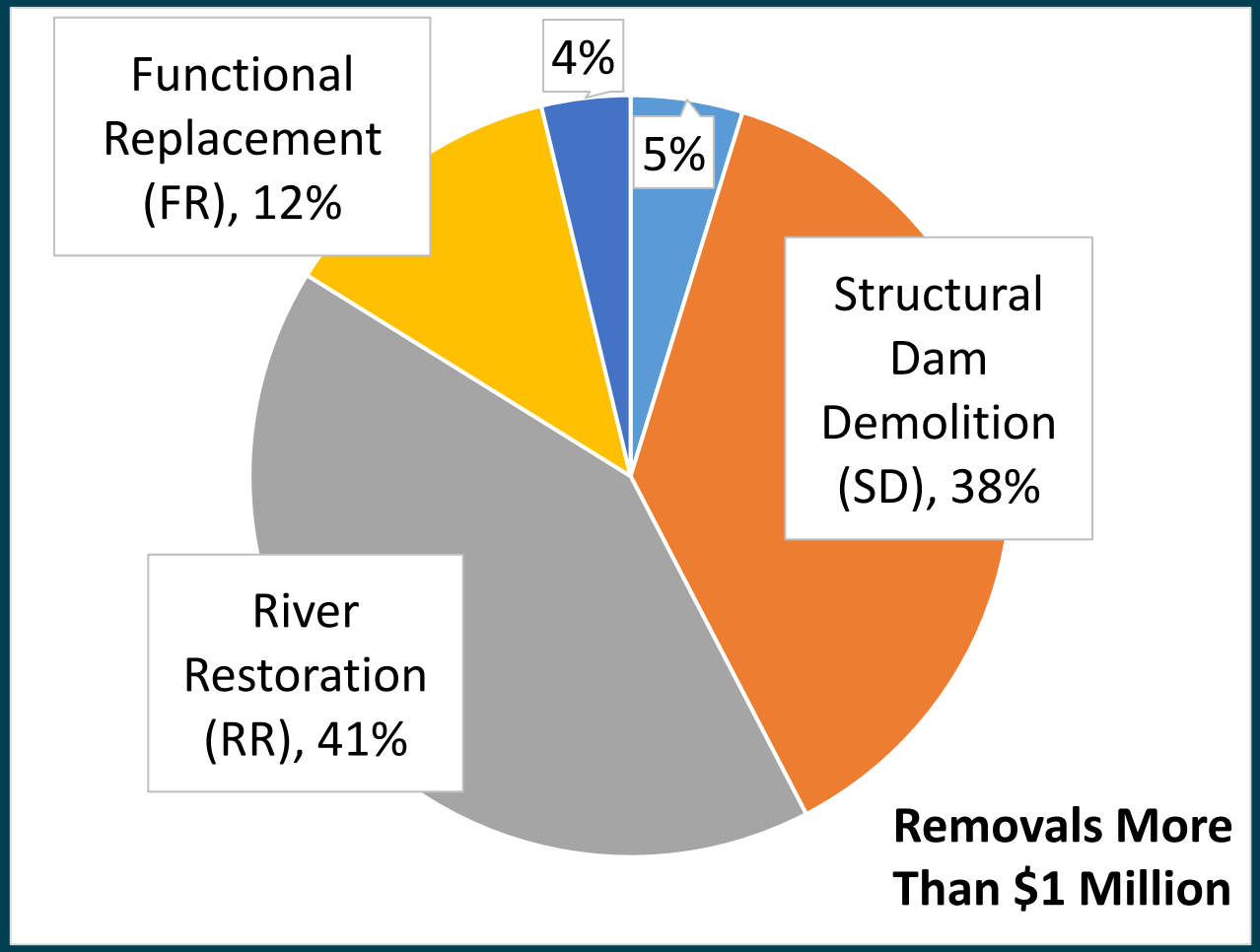
Sabin Dam prior to removal in 2018 (Photo Courtesy USACE)

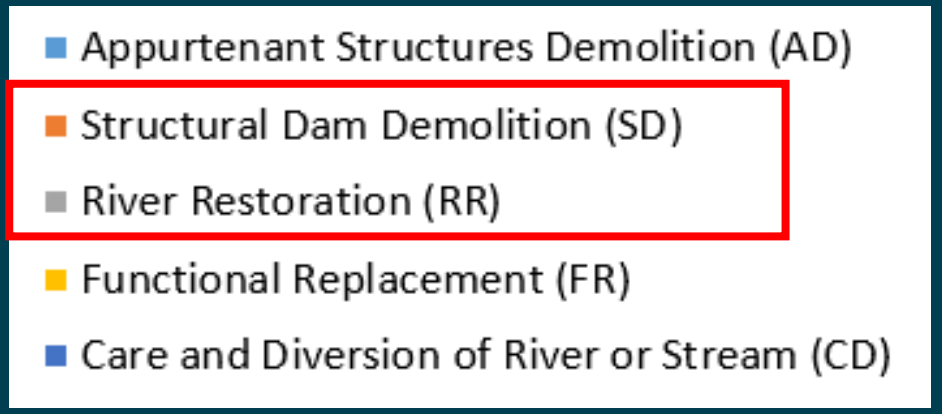
- Appurtenant Structures Demolition (AD)
- Structural Dam Demolition (SD)
- River Restoration (RR)
- Functional Replacement (FR)
- Care and Diversion of River or Stream (CD)

We created 5 categories of pay items

Construction Based Cost Drivers







Structural Demolition Pay Items

- Concrete or masonry removal
- Earth embankment removal
- Gate removal
- Use of cranes for high dams

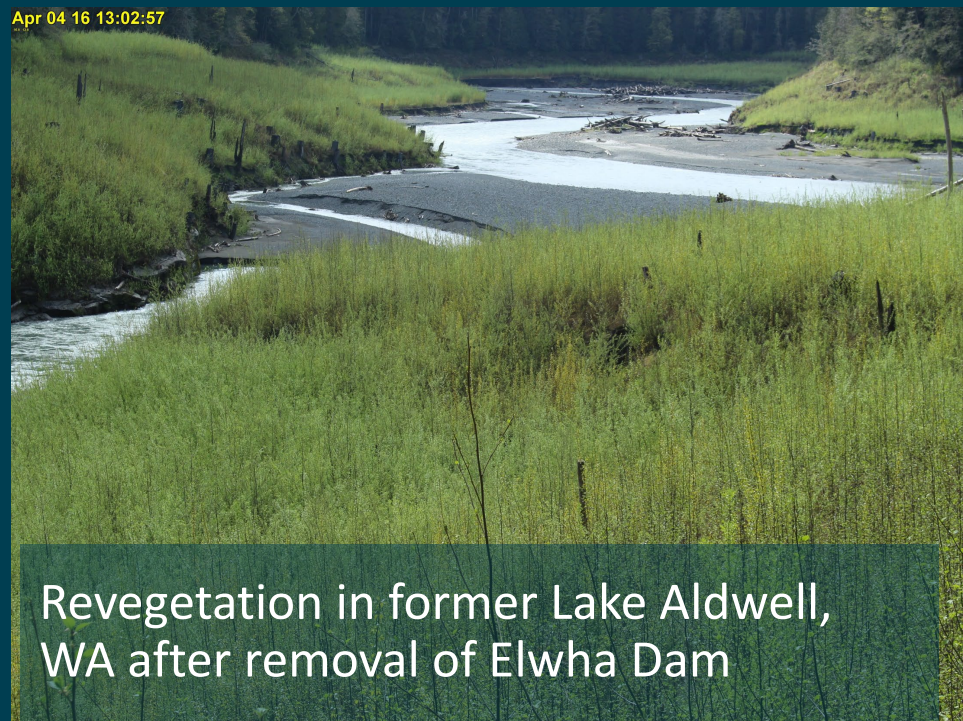
San Clemente Dam, CA,

photo courtesy of San Clemente Dam Removal and Carmel River Restoration, all rights reserved

River Restoration Pay Items

- Mechanical sediment excavation
- Pilot channel and vegetation removal
- Sediment stabilization
- Contaminated sediment management
- Hauling
- Fill or backfill
- Erosion and sediment control
- Habitat elements (large wood, fish passage)
- Reservoir vegetation or ground cover

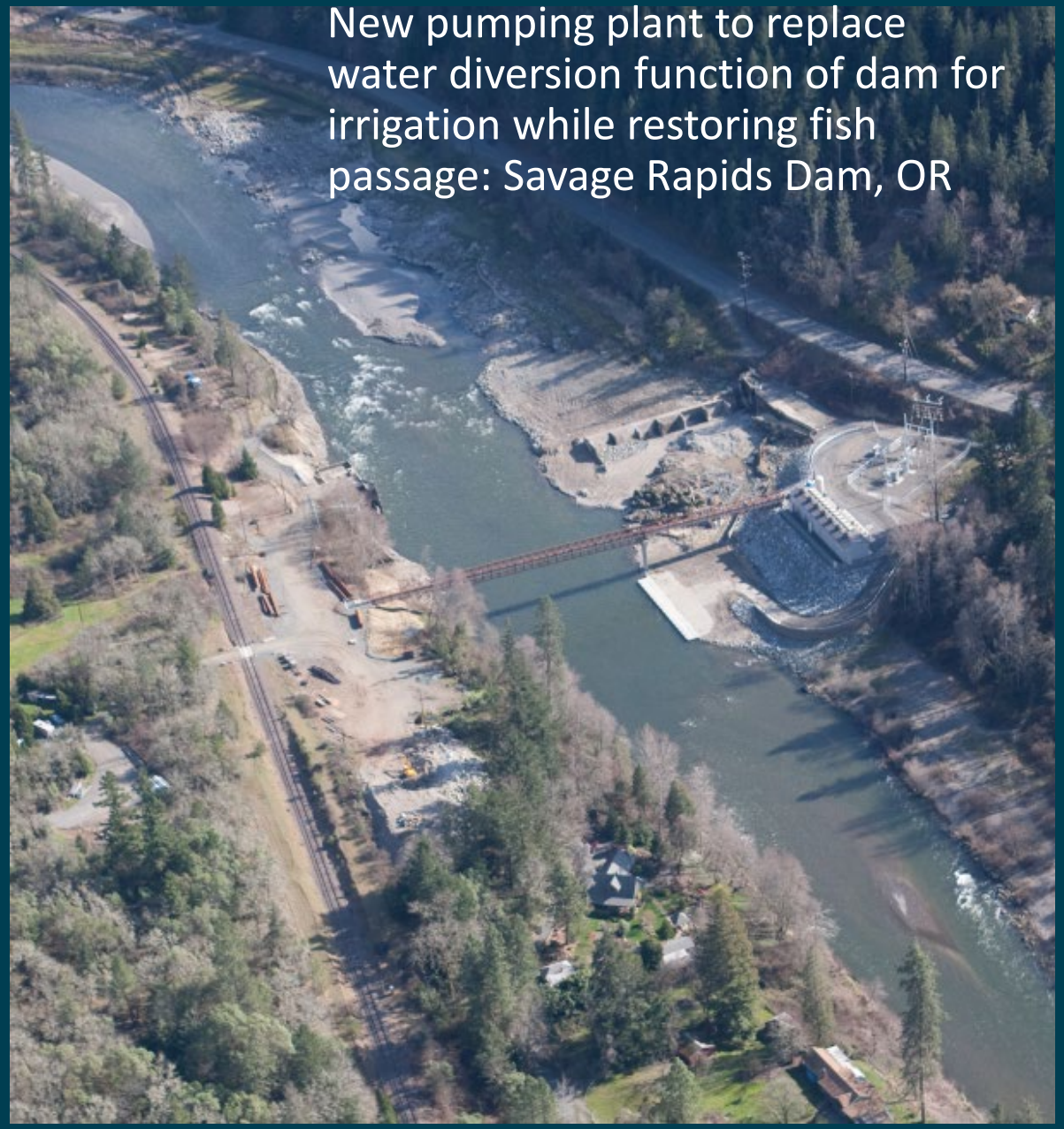
Pilot Channel in Lake Mills - Glines Canyon Dam, WA: $1M
Barge in equipment to remote location
Vegetation removal to break up roots



Revegetation in former Lake Aldwell, WA after removal of Elwha Dam

Care and Diversion of River Pay Items

- Access
- Mobilization
- Coffer Dams
- Unwatering and dewatering
- Cost of coffer dams for Savage Rapids dam removal and pumping plant construction largest cost driver $6.2M (17% of total cost)



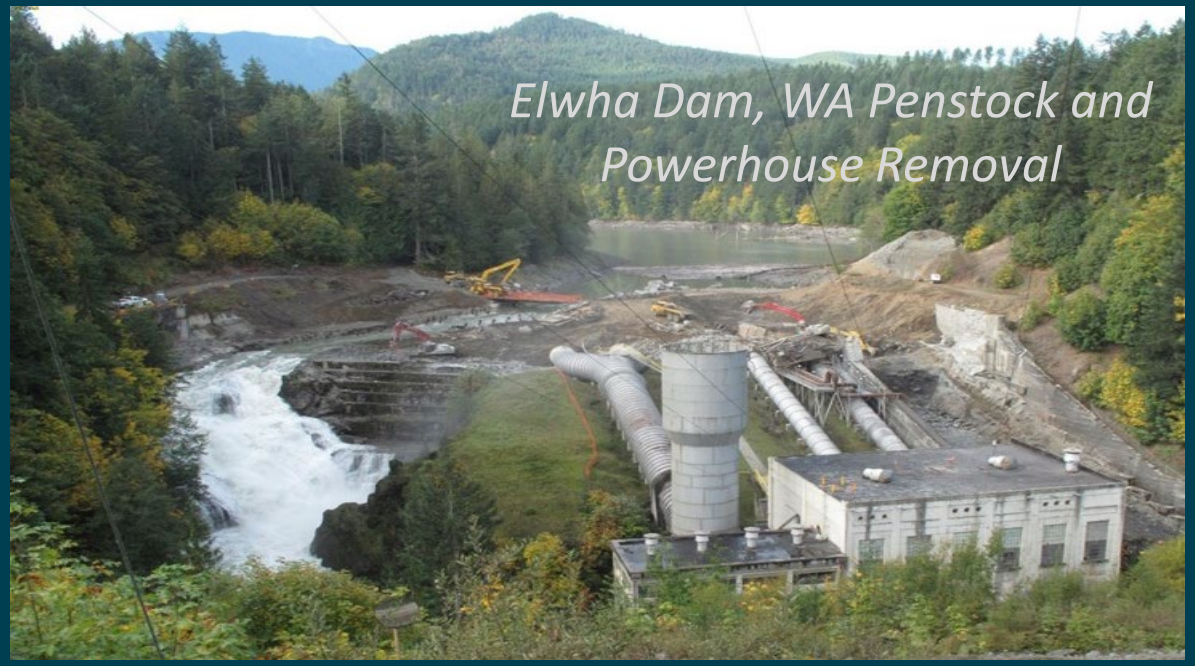
New pumping plant to replace water diversion function of dam for irrigation while restoring fish passage: Savage Rapids Dam, OR

Functional Replacement Pay Items

- New pumping plant or surface diversion to maintain water withdrawal
  - Earthwork
  - Concrete work
  - Steel work
  - Pumps and piping systems
  - Electrical work
  - Restoration of existing systems
  - Mechanical systems

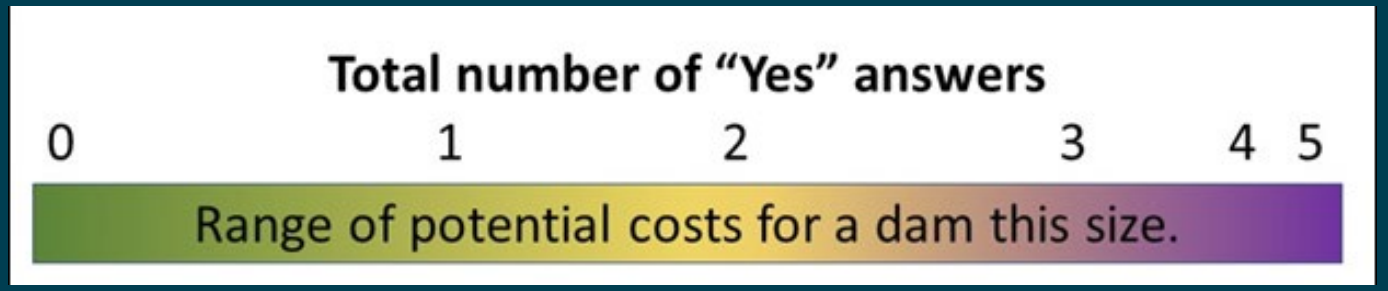
Appurtenant Facilities Demolition Pay Items

- Penstocks
- Turbines and generators
- Powerhouse and related structures
- Bridge structures



Identifying Cost Drivers: Complexity Factor

Major Cost Drivers (surrogate indicators)	Yes	No
Will more advanced construction methods be required? (coffer dam, use of cranes, dewatering, helicopters,…)		
Is sediment volume large relative to the river's sediment load? (relative sediment volume, Wriver / Wreservoir)		
Will the reservoir or dam be missed? (infrastructure replacement, litigation, stakeholder outreach)		
Will there be extensive remedial actions? (revegetation, restoration, grade control,….)		
Is there a "reason to believe" complexities will increase cost? (sediment quality, archeological sites, buried infrastructure,..)		



What degree of project definition do you need to get to an acceptable level of cost uncertainty?

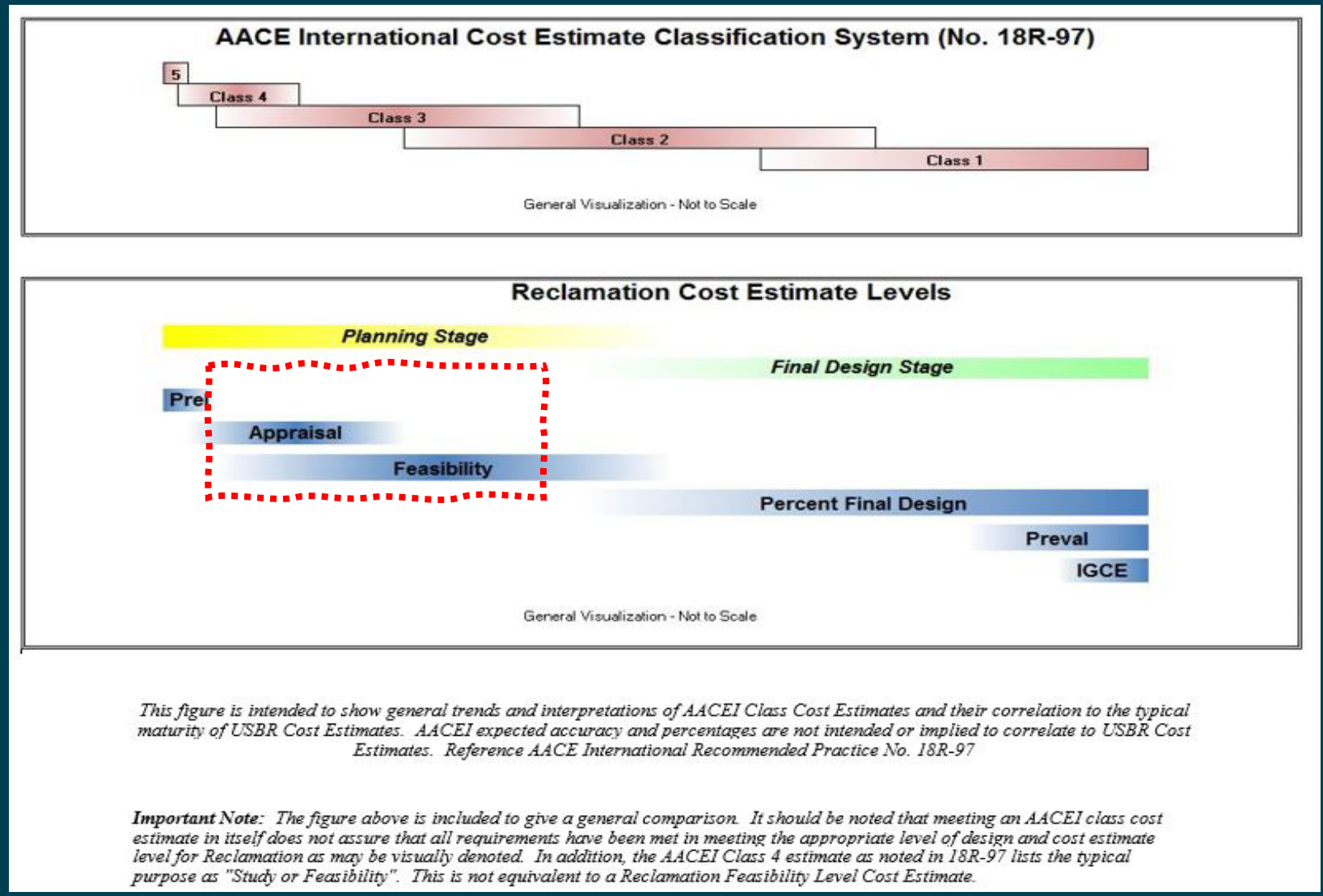
TABLE X1.1 Illustrative Example of Typical Accuracy Ranges for the Process and General Building Construction Industries

	Primary Characteristic	Secondary Characteristic	
	DEGREE OF PROJECTION DEFINITION	EXPECTED ACCURACY RANGE Typical variation in low and high ranges[A]	
Estimated Class	Expressed as % of complete definition	Process Industry	Building Construction and General Construction Industry
Class 5	0 % to 2 %	L: –20 % to –50 % H: +30 % to +100 %	L: –20 % to –30 % H: +30 % to + 50 %
Class 4	1 % to 15 %	L: –15 % to –30 % H: +20 % to +100 %	L: –10 % to –20 % H: +20 % to +30 %
Class 3	10 % to 40 %	L: –10 % to –20 % H: _10 to +50	L: –5 % to –15 % H: +10 % to +20 %
Class 2	30 % to 70 %	L: –5 % to –15 % H: +5 % to +20 %	L: –5 % to –10 % H: +5 % to +15 %
Class 1	70 % to 100 %	L: –3 % to –10 % H: +3 % to +15 %	L: –3 % to –5 % H: +3 % to +10 %

[A] The state of process technology and availability of applicable reference cost data affect the range markedly. The ± value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50 % level of confidence) for a given scope.

Dam Removal Cost Estimating Requires Up Front Data

- We found it took 40% of pay items to determine 80% of the total cost with a planning level of uncertainty
- More scope definition is needed earlier because dam removals have unique cost drivers



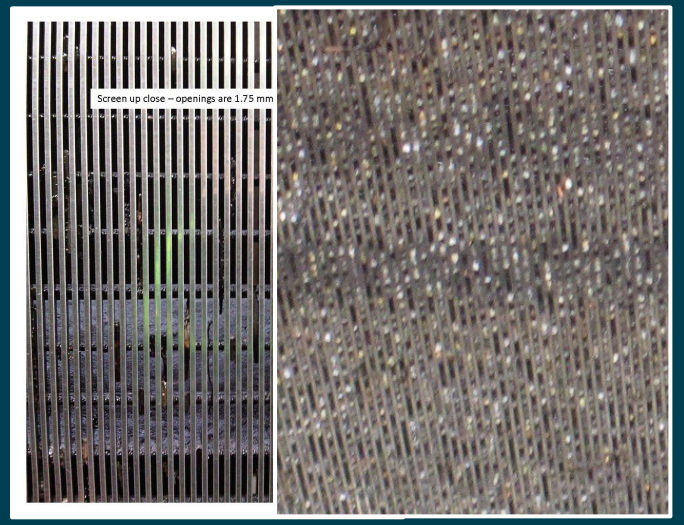
Cost Estimating Excel Tool for Dam Removal

- Requires knowing the construction means, methods, quantities, and unit prices
- Total cost is from the three categories
  - Removal of the Dam and Associated Structures
  - Reservoir Sediment Management and Mitigation
  - Reservoir Sediment Erosion and Downstream Transport Mitigation
- Provides a range of probable costs where uncertainty is reduced as scope is improved

Cost	Portion of Total	Cost Category
	1.00	Location cost factor
	0.80	Annual cost index factor
$3,310,294	48%	Removal of the Dam Associated Structures
$2,925,906	43%	Reservoir Sediment Management and Mitigation
$593,393	9%	Reservoir Sediment Erosion and Downstream Transport Mitigation
$6,829,592	100%	Subtotal
$0	0%	Non-contract costs: Design, permitting, and engineering oversight of construction
$0	0%	Litigation & Stakeholder tension studies
$6,829,592		Most Probable Total Construction Cost
$3,414,796		Probable Low Total Construction Cost

Outcomes from work

- Scoping questions to identify potential complexity cost drivers
- Regression tree to estimate dam removal cost range
- Databases for case study comparison to dams with similar cost drivers, river magnitude, and geographic context
- Planning level Excel tool – requires initial engineering plan for dam removal, knowledge of potential mitigation, and unit costs for pay items



Cost Savings to Consider

- Early reservoir sediment management in dam lifecycle planning can reduce cost driver issues later if decommissioned
- Allowing river to do the transport work and repurposing sediment within former landscape
- Allowance of in-water work and avoiding cofferdams
- Develop local vegetation sources for replanting and work with local volunteers
- Collaboration, communication, and adaptive management approach to work with stakeholders and partners
- Streamlined permitting and regulatory processes

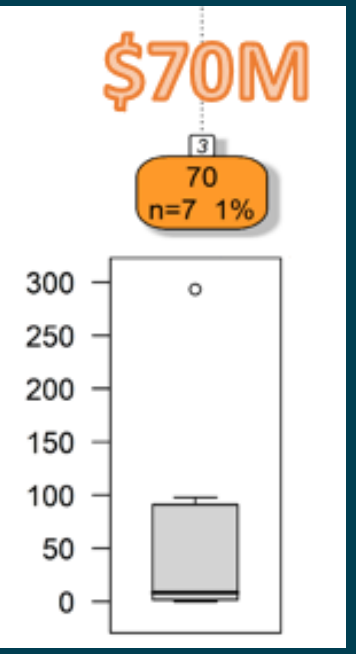

Reservoir Sedimentation Matilija Dam, CA

Case Studies Exercise – Name that Cost $$$$

Birch Run Dam, near Fayetteville, Pennsylvania
Northeast

- The 19.5-m (64 ft) high, earth-fill dam provided water storage
- Most unsafe dam in state (inadequate spillway)
- Drivers: none
- Avg Annual Flow: 23 cms (812 cfs)

Birch Run Dam, near Fayetteville, Pennsylvania Northeast (2)

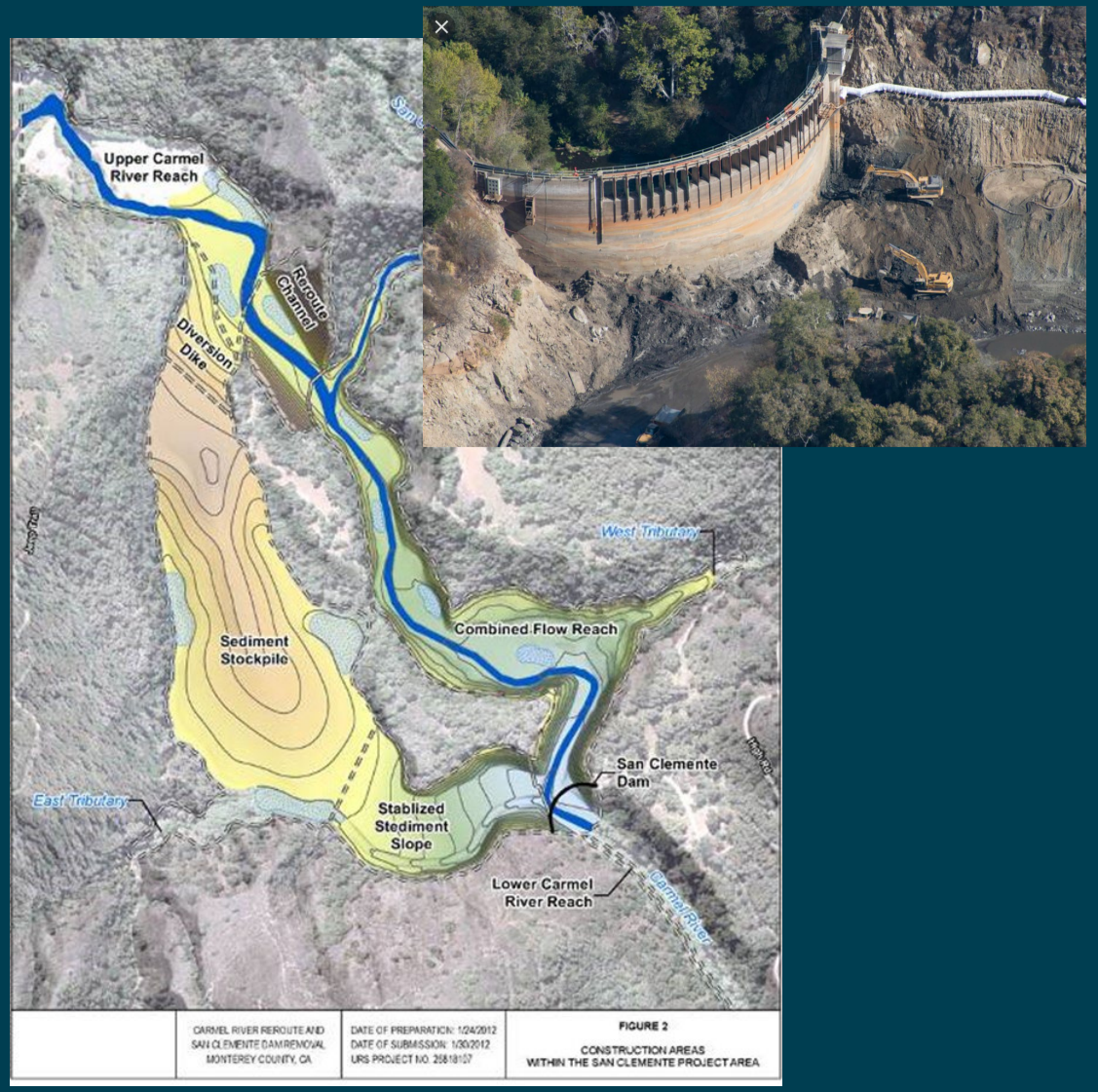


- The 19.5-m (64 ft) high, earth-fill dam provided water storage
- Most unsafe dam in State (inadequate spillway)
- Drivers: none
- Avg Annual Flow: 23 cms (812 cfs)
- Cost saver: permitting process streamlined by the PADEP Stream Restoration Authorization

Cost: $2.1 M

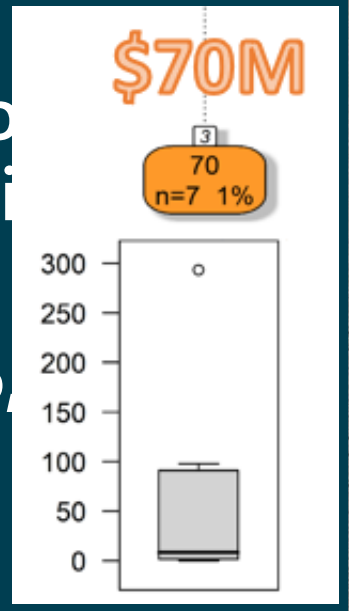
San Clemente Dam near Carmel, California
Northwest

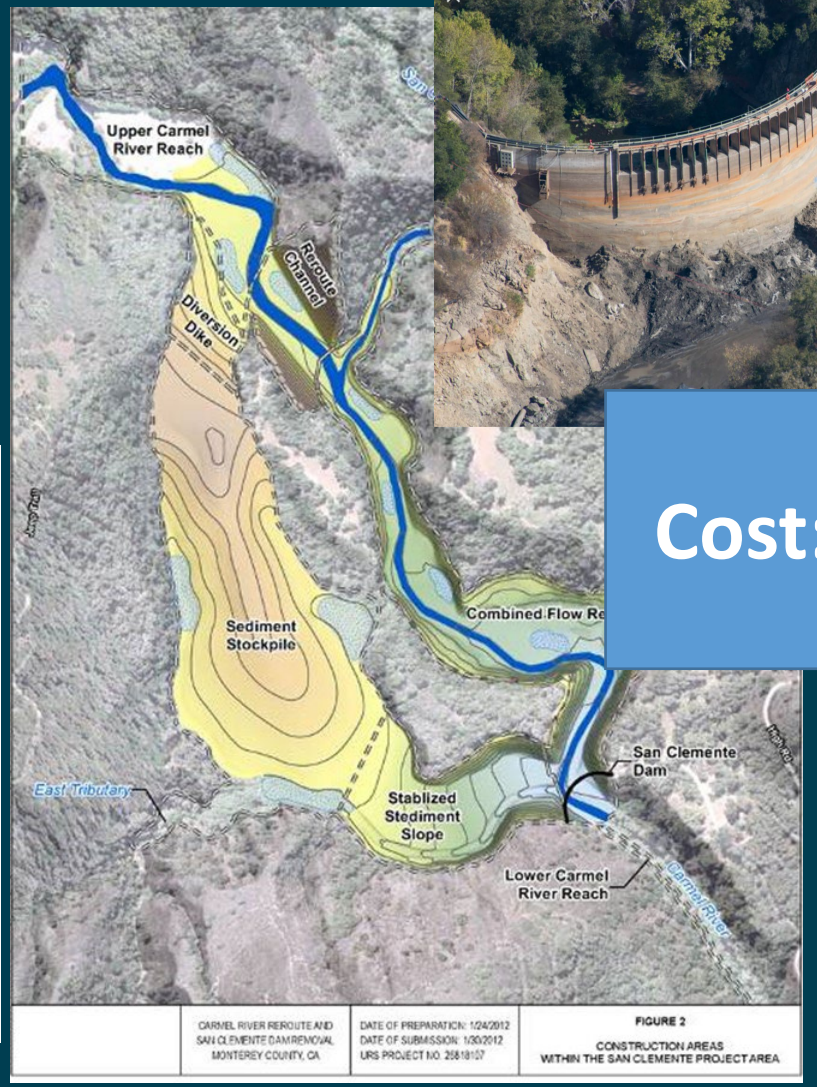
- The 32-m (104 ft) high, concrete arch dam for water supply
- Reservoir filled with sediment and dam considered unsafe from floods and earthquakes
- Drivers: sediment stabilization, cofferdam, fish passage/habitat, difficult access
- Avg Annual Flow: 170 cms (6,000 cfs)



San Clemente Dam near Carmel, California Northwest (2)

- The 32-m (104 ft) high, concrete arch dam for water supply
- Reservoir filled with sediment and dam considered unsafe from floods and earthquakes
- Drivers: sediment stabilizatio cofferdam, fish passage/habi difficult access
- Avg Annual Flow: 170 cms (6,





Cost: $98 M

Bluebird Dam, Rocky Mountain National Park, near Estes Park, Colorado
Southwest

- The 17.1-m (56 ft) high, concrete dam provided water storage
- Dam was leaking and severely deteriorated
- Drivers: revegetation, helicopter access required
- Avg Annual Flow: 2.2 cms (79 cfs)

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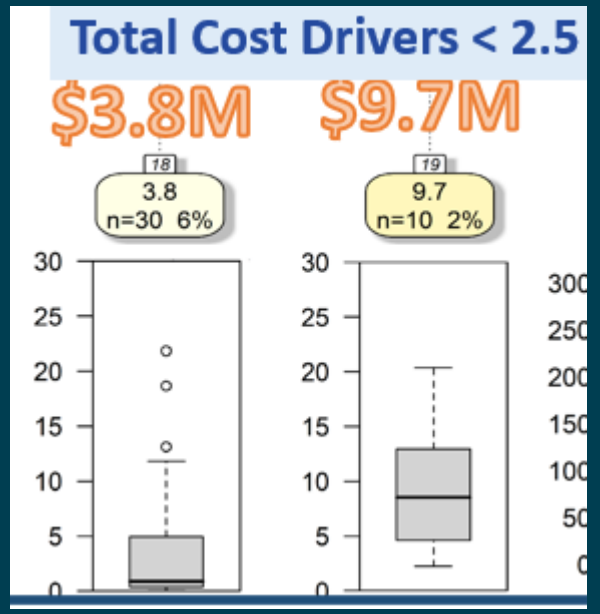

Cost: $8.5 M

Image: Brian Cluer