Using GIS to Identify Hydraulic Structures in Irrigation Canals

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RECLAMATION
Managing Water in the West
U.S. Department of the Interior
Bureau of Reclamation

Northern Water

Welcome!

- Summary:
  - There is an interest to identify the available power potential of constructed waterways
  - An investigation into this development begins at existing hydraulic structures
  - A complete list of existing hydraulic structures in constructed waterways, similar to the National Inventory of Dams, does not exist
  - While site visits to every potential hydropower site is desirable, it is impractical to perform such a survey across Colorado, let alone a multi-state region
  - Data requests from regional field personnel to identify potential micro hydropower sites have not been completely successful

Buckeye Water Conservation District
Head = 2.6 m
Power = 9.60 **kW**

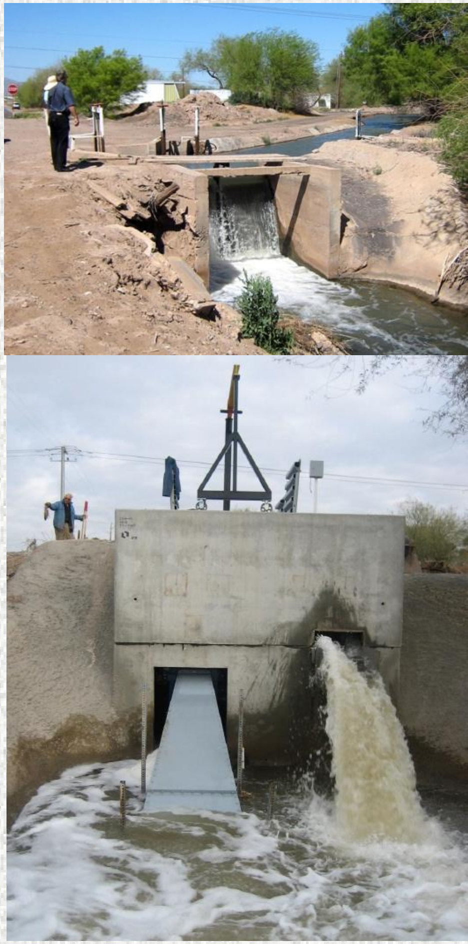


Image from : www.natelenergy.com

Summary

- Two Studies
  - Scope:

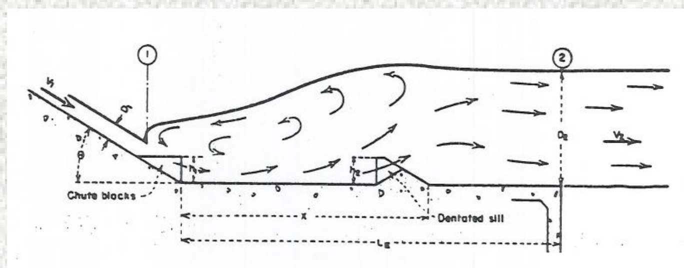
(1) Explore as many sites as possible in Colorado and report findings

(2) Investigate GIS profile signature for sites of interest using data from publically available resources

- Guiding questions include…
  - What types of structures exist?
  - How to identify and count these structures using existing data?

Introduction and background

- Why irrigation canals?
  - Very flat thalweg slopes are typically used in canal design to maintain a subcritical flow regime and in turn maintain hydraulic control
    - Prevents high shear stress on canal lining
  - Hydraulic structures are implemented to maintain hydraulic control dissipate excess energy with steep grade change
  - Minimal site upgrades required… low impact



Stilling Basin for Spillway Flow Energy Dissipation (USBR)

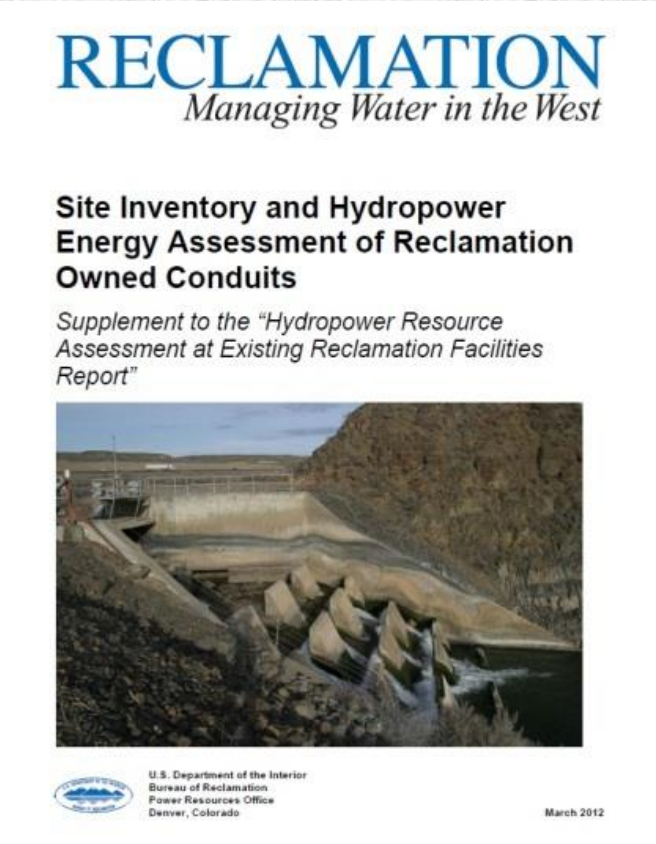
$$\left(\frac{dm}{dt}\right)_{Syst} = \frac{d}{dt}\int_{CV} \rho dV + \int_{CS} \rho(\vec{v} \cdot \vec{n}) dA$$

$$\sum \vec{F} = \frac{d}{dt}\int_{CV} \vec{v}\rho dV + \int_{CS} \vec{v}\rho(\vec{v} \cdot \vec{n}) dA$$

$$E_1 = E_2 + h_L$$

Previous Assessments

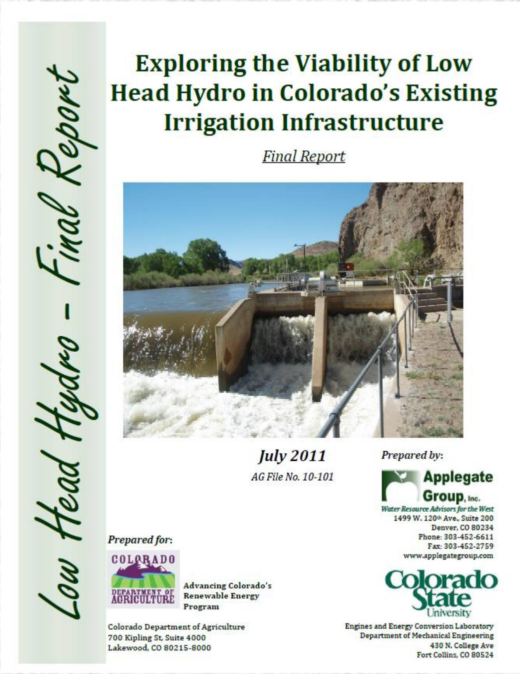
- United States Bureau of Reclamation
  - Focused on USBR owned conduits
  - Elevation changes >= 5 feet, flow period >= 4 months



	Number of Projects	≈Available (MW)
17 Western States	373	104
Colorado	28	27

Previous Assessments

- Department of Agriculture ACRE Program
  - Applegate and CSU teamed to study development of small hydro in existing irrigation infrastructure
  - Among the objectives included an assessment of state wide low head hydropower potential and in-depth catalogue of existing technology for low head applications
- Data collection methodologies
  - Survey (mailed, email, hand delivered)
  - Public outreach
  - Yielded low response (reason unclear)
- Conclusions included:
  - Need for field researcher to address this question



Study 1: Colorado Field Investigation

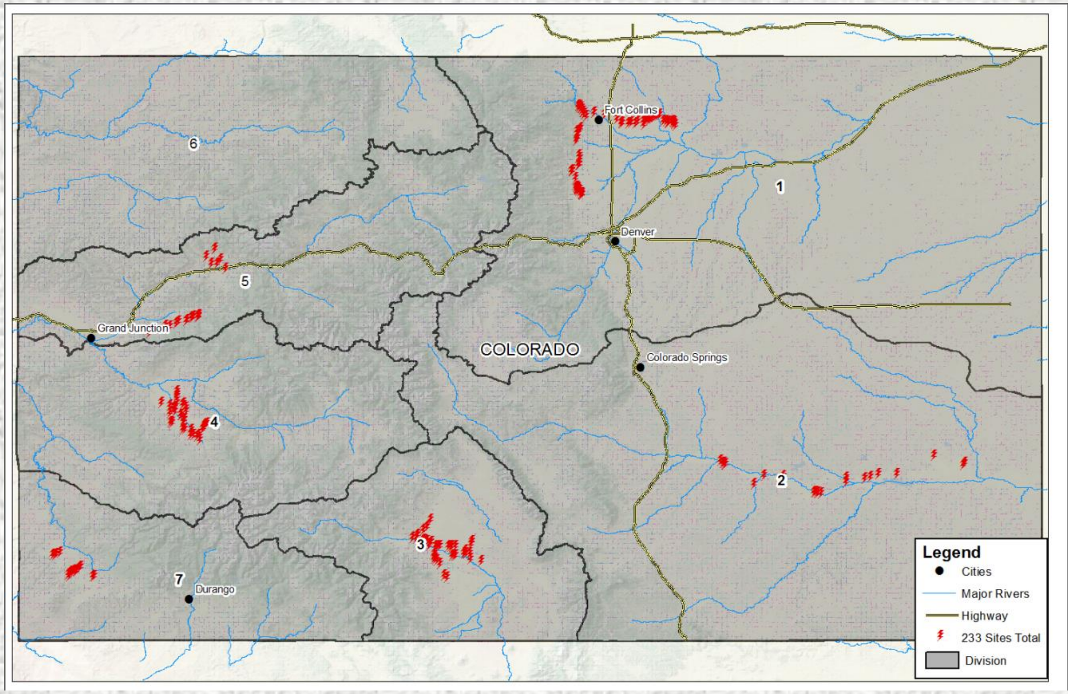
 +  +  =

- 6 of Colorado's 7 drainage divisions explored
- 745 kilometers of canal
- 233 hydraulic structures
- 1 flat tire



Scope

- Physical Data Collection
  - Goal was to obtain representative selection of structures used in the field, not to conduct a comprehensive study of the area
  - Preselected probable canals from CDSS to minimize travel and save $
  - Used aerial imagery to find sites on the canals
  - Contacted area Water Commissioners to find contacts in the field
  - Drove to sites and documented

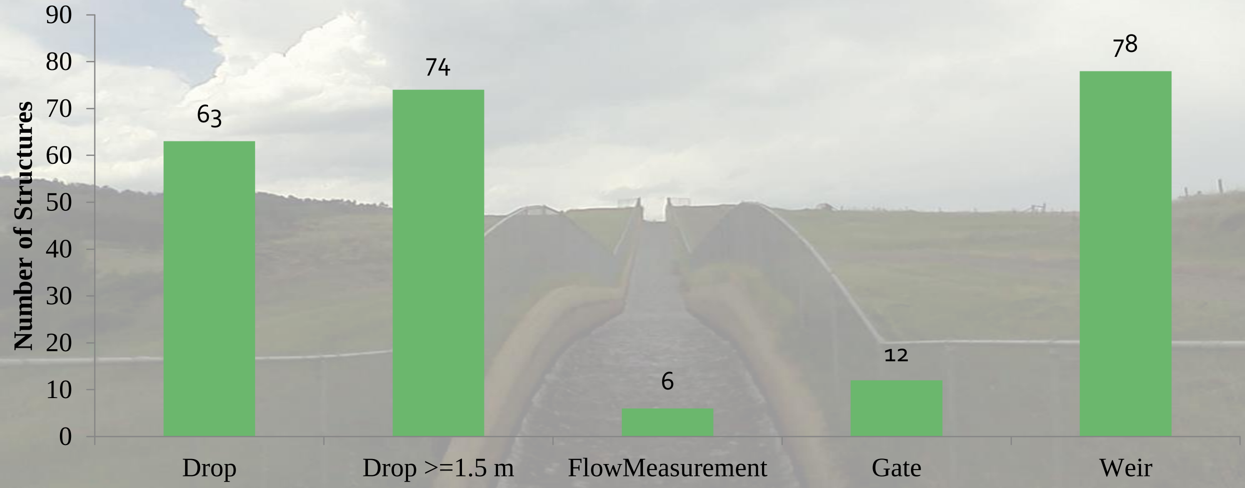


Methodology

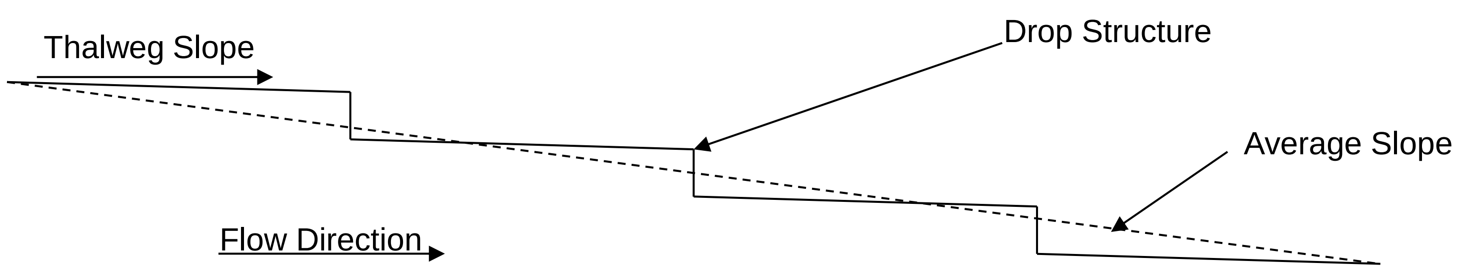
- Simplified categories for management of data
  - Drops
  - Weirs
  - Gates
  - Flow Measurement Structures


- Field data collected included
  - Total available head
    - Surface to surface
    - Water mark when dry
    - As-Builts when available
  - Location to nearest utility connection
  - Flow records if existed
  - Pictures and documentation
  - Structure type
  - Location relative to flow


Analysis and Results



- Gross Head = 956 meters
- Flow Rates = Not as easily accessible



Analysis and Results

Region	Average Slope of Region (%)	^Drops	^Drops >= 1.5 m	^Gates	^Weirs
2	0.042%	0	3	1	2
1B	0.059%	13	1	1	27
3	0.145%	9	0	2	23
4	0.299%	8	10	1	7
1A	0.375%	15	35	5	12
7	0.441%	14	69	0	5
5	0.741%	0	36	2	1

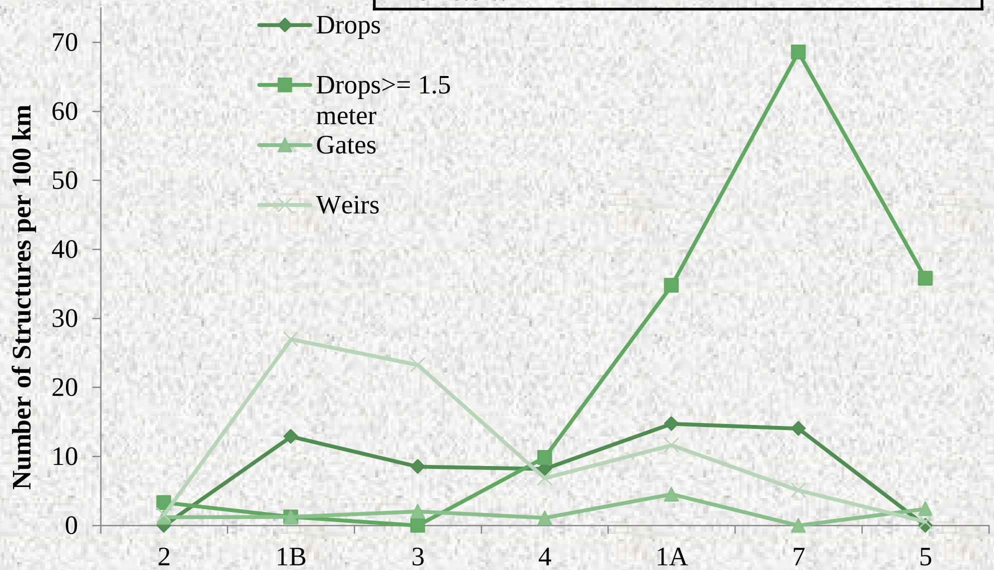
*This table excludes data from turnout structures.
^Value reflected is the average number of structure type per 100 km of alignment length.

^Elevation change per 100 km from Structures >= 1.5 m
11
7
0
131
297
224
501

^Averaged of elevation change from structures >= 1.5 meters in each canal within the region per 100 kilometers.

Power Potential (kW)				
	Flowrate (cfs)			
Head (m)	50	100	500	1000
50	591	1181	5907	11814
100	1181	2363	11814	23627
500	5907	11814	59068	118136
1000	11814	23627	118136	236271

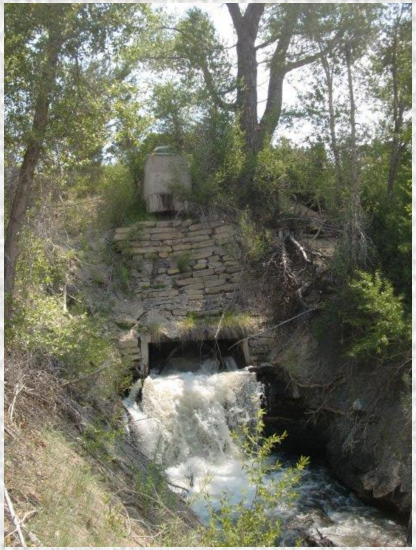
*Power potential reflected assumes an 85% efficiency



- At this time, this method lacks flow rate/duration data.
- Only anticipate applications include assumed structure counts and estimate gross head measurements

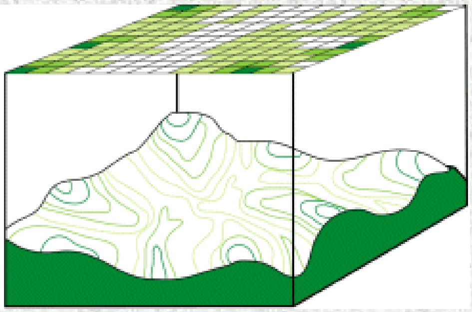
Lessons Learned

- Not large sample
- Results are specific to this dataset… but it's a start
- One could trace every canal by aerial photography, time intensive and not every site is shown

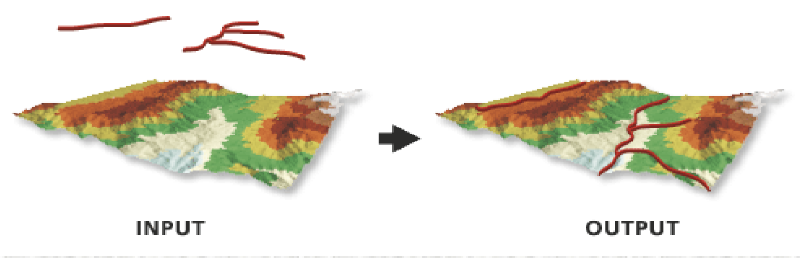


Study 2: GIS Investigation

- National Elevation Dataset (NED)
  - Compiled of best available DEM data
  - 30 meter, 10 meter, and 3 meter resolution available
  - Elevation values are average of tile
    - Surrounding area affects measurement
    - Smaller tile = better measurement = more time
  - Relative accuracy between nodes ± 1.64 meters (2003)
    - Anticipated to get better with time
  - FREE!

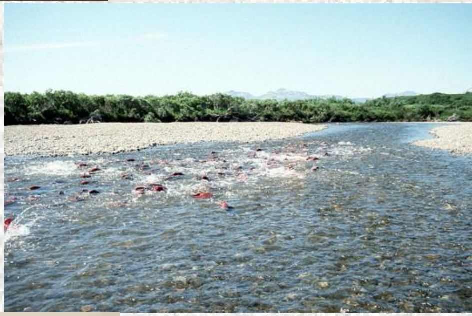


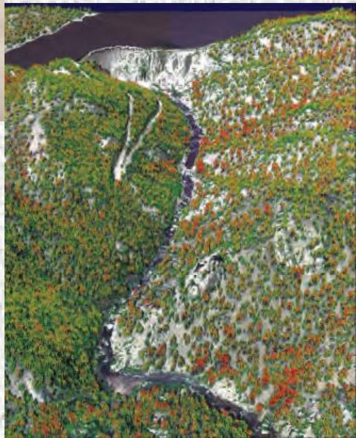
- National Hydrography Dataset (NHD)
  - Surface water component of National Map
  - Provides alignment data
  - Digital vector dataset containing features for
    - Lakes
    - Streams
    - Rivers
    - Canals
    - And more…



Study 2: GIS Investigation

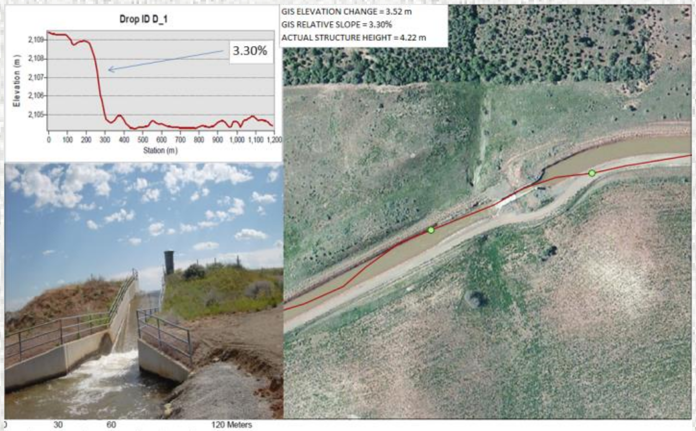
- Examples of NED applications
  - Transportation
  - Drainage calculations
  - Salmon
  - Terrain maneuver/Terrain Features
- Limiting factor for accurate data is cost
  - Light Intensity Distance and Ranging (LIDAR) Vertical Accuracy can be within 15 cm!! $$

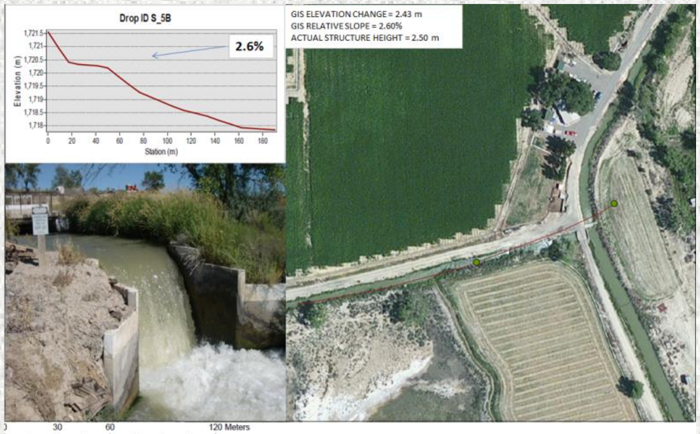



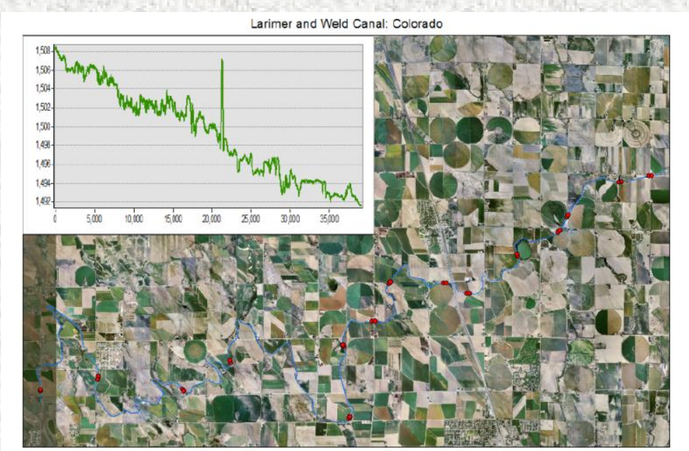


Study 2: GIS Investigation

- Investigating the NED/NHD interface revealed a profile signature does exist… sometimes
- Elevation changes recorded from the NED are correct… sometimes



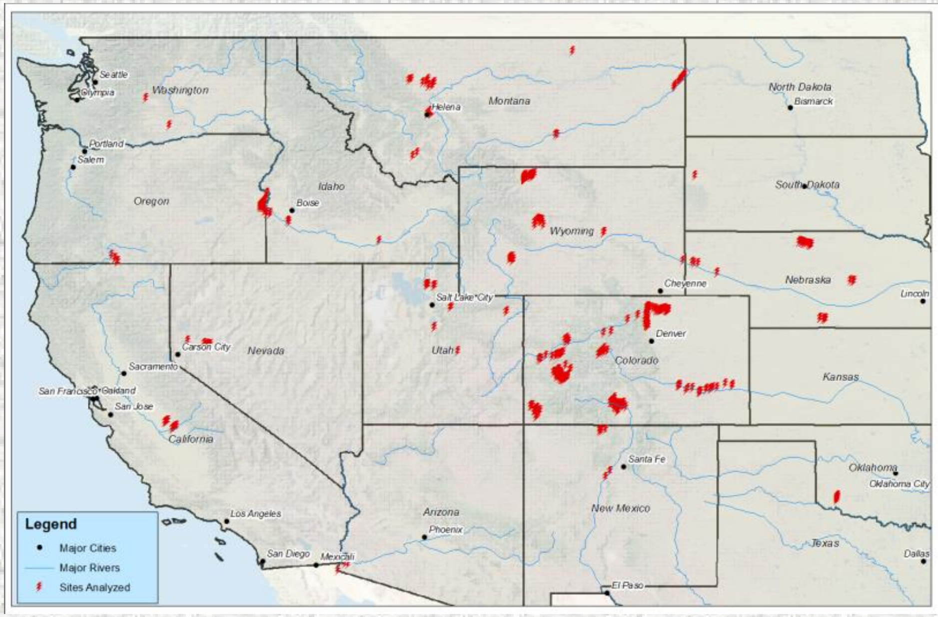


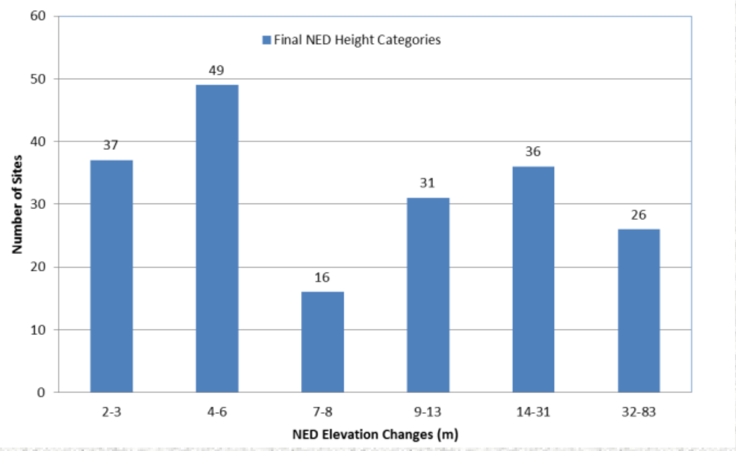


- Scope
  - Investigate NED/NHD interface and create a GIS model for identifying structure locations in canals by identifying their profile

Methodology

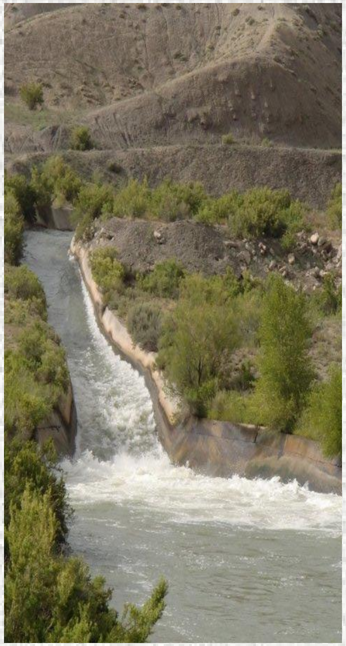
- Dataset Analyzed (195)
  - USBR contributed sites from 2012 report
  - Variables included
    - Gross height
    - Distance of measurement
    - Average slope of surrounding terrain
  - Elevation values were binned to 1 meter increments
  - Only analyzed sites >= 2 meters
    - This eliminated all weirs, gates, and flow-measurement structures
  - NED Height Categories were created to analyze clusters of sites

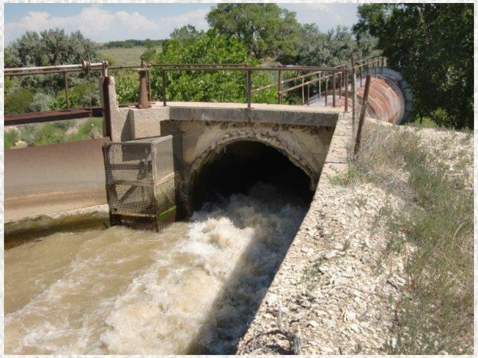




Methodology

- Hydraulic structure sub-categories
  - Drop
    - Vertical (79)
    - Chute (58)
    - Series of drops (33)
    - Pipeline (16)
    - Steep grade change (9)



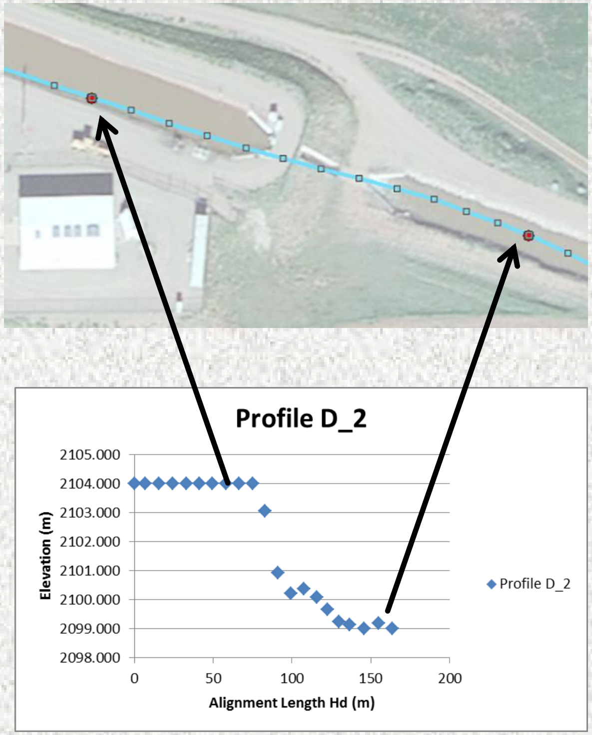


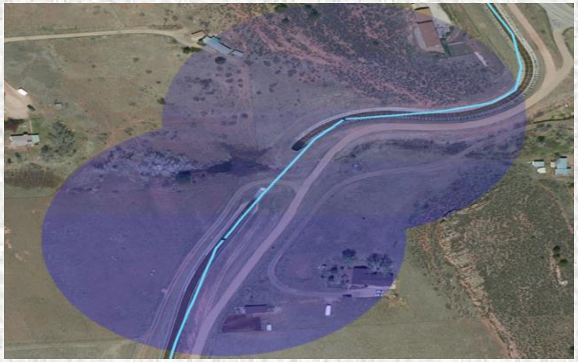
Methodology

- Using ArcGIS
  - High Resolution National Hydrography Dataset (NHD)
  - 10m National Elevation Dataset (NED)
  - Downloaded and projected

- ArcGIS data collected included
  - Elevation change across the structure
    - This was done 40 and 70 meters US and DS of Structure
  - Surrounding average slope
    - 100 meter and 500 meter (this plays a role in value of NED)

- Data was exported from ArcGIS for further detailed analysis

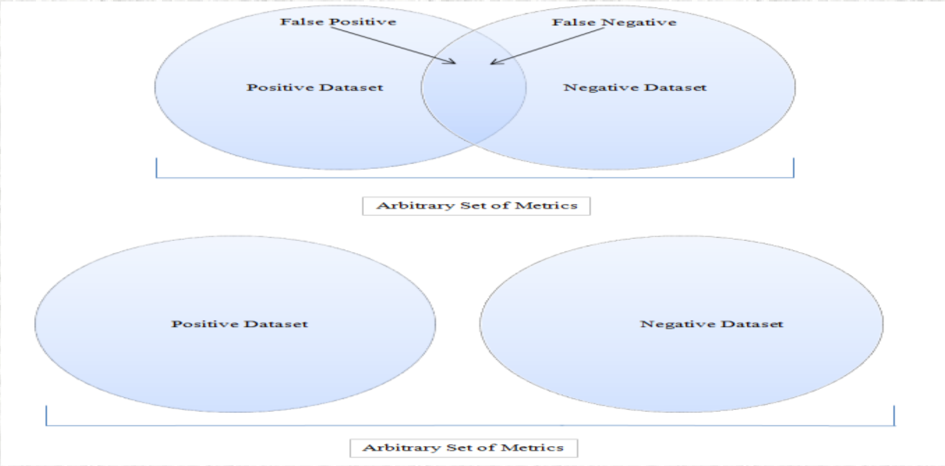




Analysis and Results

NED Site BIN (m)	Acceptable Error (m)	Number Non-Successful Sites	Number Successful Sites	Total Sites
2-3	2	12	25	**37**
4-6	2	17	32	**49**
7-8	2	5	11	**16**
9-13	2.5	14	17	**31**
14-31	4.5	10	26	**36**
32-83	5	10	16	**26**
	Total	**68**	**127**	

Error = | Field Measurement – NED Measurement |



- Task is to systematically select metrics that minimize false positive and false negative while maximizing the percent correct!

- To build the GIS model, need to answer the question:
  - Why do some sites have an accurate measurement from NED and others do not?
- Separate each site into its 3 variables as defined by
  - Length
  - Elevation Change
  - Average Surrounding Slope
- Used a histogram analysis to identify an acceptable error range for each cluster
- Used False Positive and False Negative statistics to analyze each variable

Analysis and Results

- An algorithm was derived that produced the following results for the data sample used

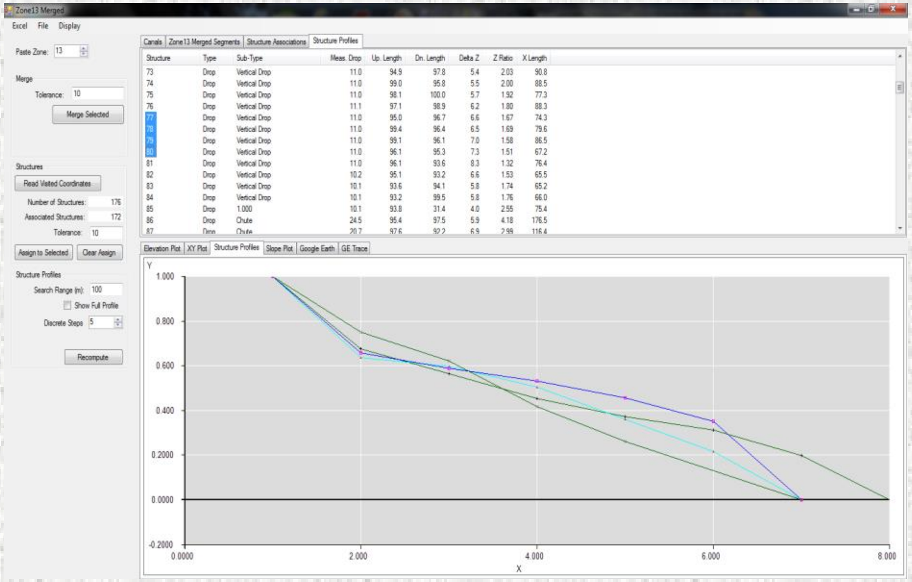
NED Site BIN	Min Length	Max Length	100m Radius MIN	100m Radius MAX	500m Radius MIN	500m Radius MAX	Probability of Correct Selection
2-3	50	130	2.00%	11.75%			86%
4-6	50	320	4.50%	16.00%	3.00%	12.00%	71%
7-8	50	460	9.00%	13.50%	2.00%	6.50%	88%
9-13	50	290	7.50%	12.50%	5.00%	8.25%	81%
14-31	50	920	11.75%	28.00%	2.25%	20.75%	75%
32-83	50	2350	29.25%	32.25%	5.25%	12.75%	77%

- WHAT DOES THIS MEAN?
  - When the algorithm is applied to a 3 dimensional NHD alignment AND…
  - An elevation change equal in magnitude to the NED site bin is witnessed AND…
  - All components of the algorithm are met THEN…
  - The probability of a potential micro hydropower site in the location will be equal to the listed value for said NED site bin

- Bias assumes the dataset is sufficiently diverse and would produce same results if observed with larger dataset. More data is desired to fine tune model

Future Work

- Comments and Discussion
  - The algorithm is specific to the collected dataset developed to maximize the probability of sorting the existing data correctly
  - Test GIS model with data and field validation exercise. Fine tune
  - What to do about flowrates?
  - Explore data specific to categories. Use profile signature to identify category of data count the number and type of structures in a region



This is the first method of this type to analyze power potential in irrigation canals.

Summary

- There is a significant interest in incorporating micro hydropower into renewable generating asset portfolio
- Previous studies have been shown to be incomplete
- Data requests from regional field personnel to identify micro hydropower potential have been unsuccessful. While site visits to every potential hydropower site is desirable, it is impractical to perform such a survey across Colorado, let alone a multi-state region
- It is shown that using publically available GIS resources, potential micro hydropower sites can be identified within a calculated probability
- Future work will continue!

Acknowledgments

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THANK YOU!