The Impact of River Flow on Microhydroelectric Power Generation

A Case Study of the Burnshire Dam: Woodstock, VA

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ISAT 493
April 15th, 2016

Origin of the Project

- Our work with Burnshire Dam owner, Dr. Lee Harvey began long before the project we are presenting today
- Hurdles kept arising and we were forced to entertain our options
- Dr. Harvey mentioned to us the implications of his dam downstream and a crisis the community had faced
- Wanted to know more of how he could help

Water Shortages

- Strasburg, Virginia
- Water Crisis of 2015
- Drought watch and warning issued
- What are the available options?

Image Source: http://deadspin.com/5555518/town-offers-to-rename-itself-stephen-strasburg

Drought Warning

- http://moderator.droughtreporter.unl.edu/RSSfeed/ImpactView/32165

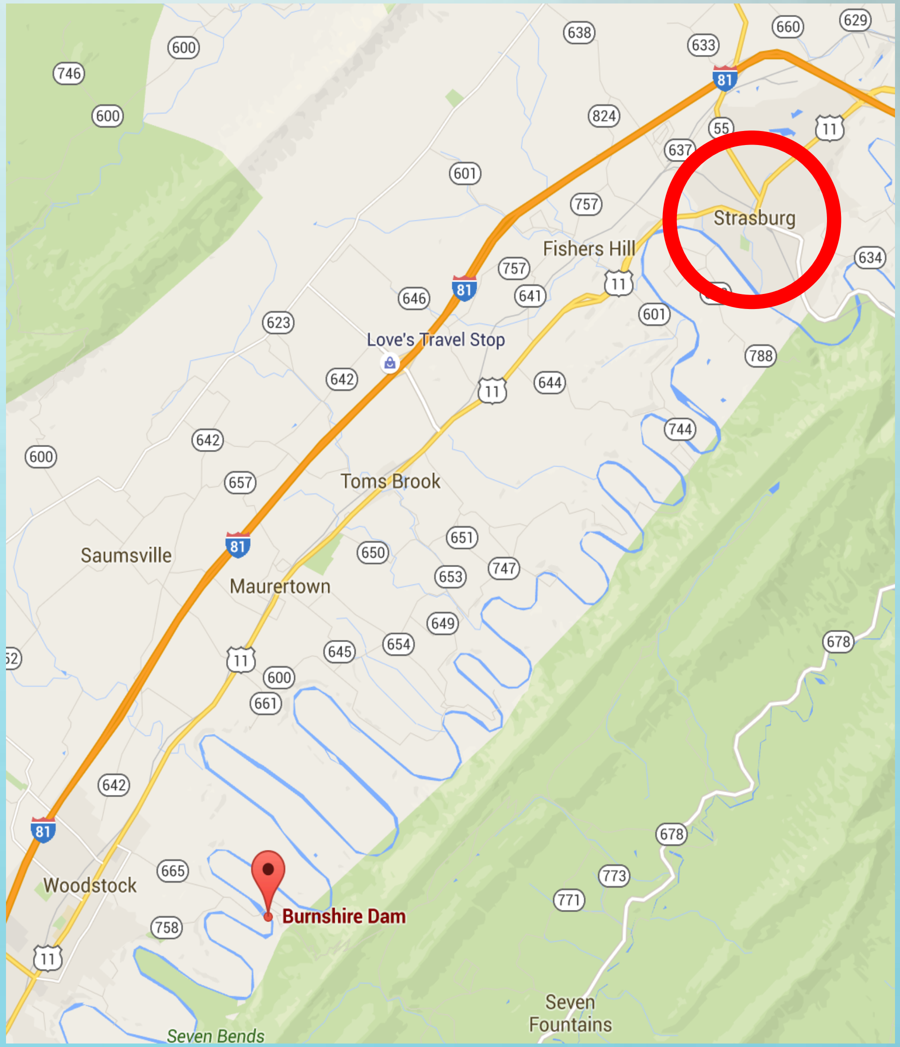
Drought warning in Strasburg, Virginia
9/2/2015 4:28:37 PM

Start Date: 7/28/2015 - End Date: 8/21/2015

Strasburg's drought watch turned into a drought warning on Aug. 21 when the river flow fell to 111 cubic feet per second, compared to a normal level of 175 cubic feet per second. Water conservation was voluntary. Charlottesville Daily Progress (Va.), Aug. 31, 2015 Strasburg declared a drought watch on July 28 because the 7-day average flow of the Shenandoah River dropped to 173 cubic feet per second, below the drought watch trigger of 175 cubic feet per second. Residents were asked to limit water use. Northern Virginia Daily (Strasburg, Va.), July 28, 2015

Initial statement of the problem

- Meeting of interested parties to discuss the issue
- Incorrect Calibration of the USGS Gauge
- "What if?"
- Is the Burnshire Dam a viable source of water?
- Legally, can the impoundment of the Burnshire Dam serve as an emergency water supply?



Conventional Dams

- Reliable and efficient way to generate electricity
- Typically people picture the Hoover Dam
- Stakeholders Include:
  - Aquatic ecosystems
  - Human communities
  - Downstream watershed
  - Power users
  - Government regulators

http://www.alternatieve-energie-info.be/waterkracht-energie/

Small Hydropower

- Classified as any hydropower facility producing less than 30MW of power according to the U.S. Department of Energy
- Small enough and customizable design to adapt to almost any land scape which allows for power generation in remote locations
- Typically used to manage water flow on a lake or river (Kosnik 2010)

Image Source: http://www.thehea.org/basic-principle/hydro-power-plants/

Image Source: https://www.asdreports.com/market-research-report-30283/small-hydropower-shp-installed-capacity-levelized-cost-energy-lcoe-competitive

Run of the River Hydropower

- Diverts a portion of the waterway from the natural river channel into the
- Uses the natural flow and drop of the river to generate hydraulic head
- Very little impoundments if any at all

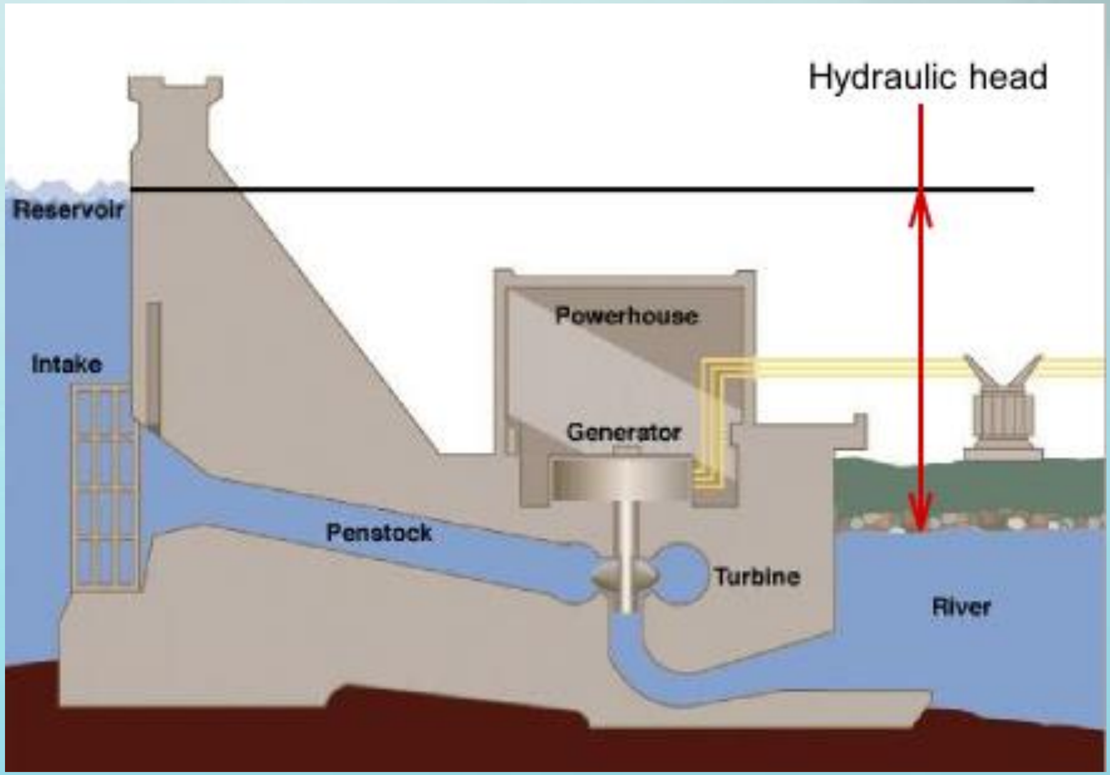
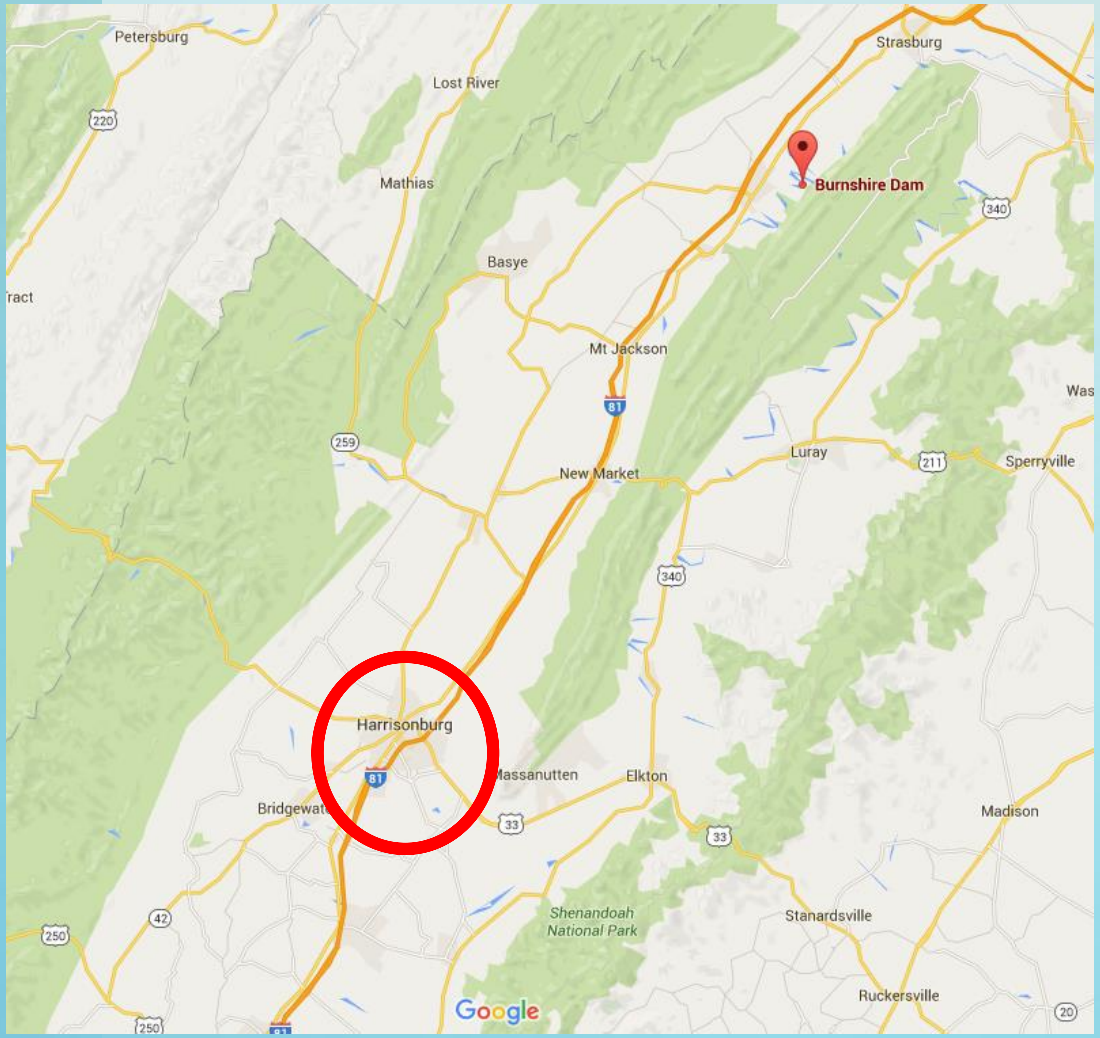
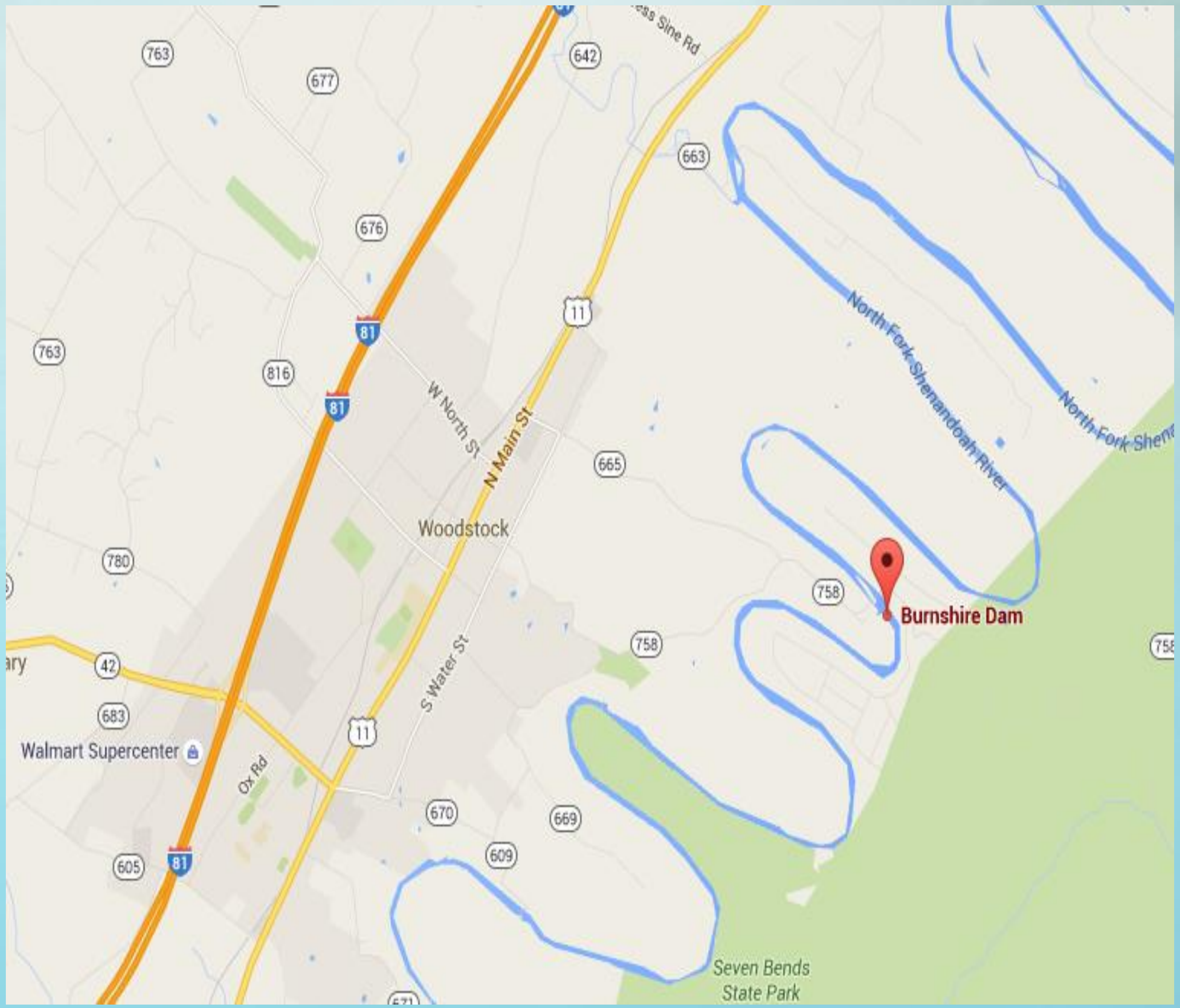


Image Source: https://upload.wikimedia.org/wikipedia/commons/a/ae/Hydraulic_head.PNG

Burnshire Hydroelectric, LLC

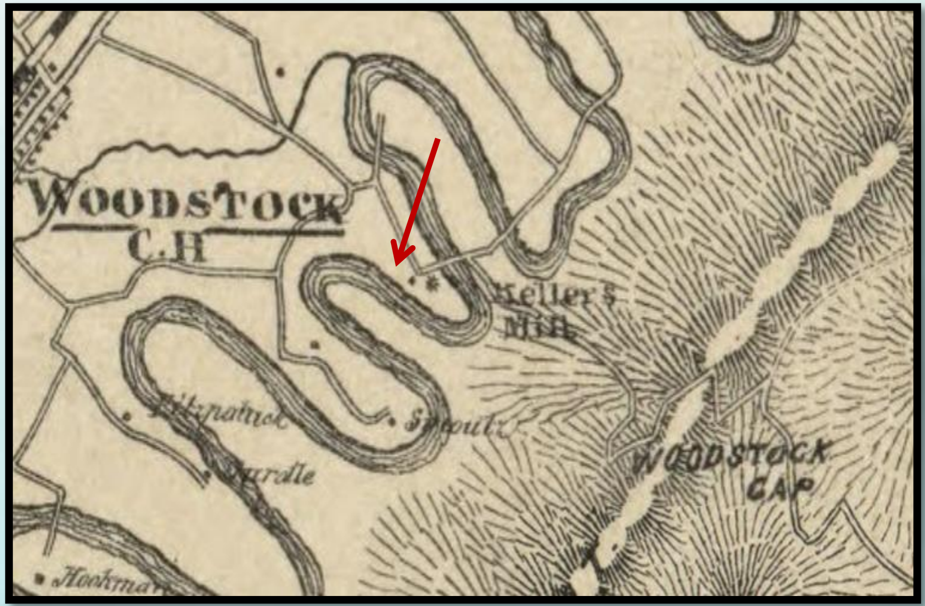
Burnshire Location



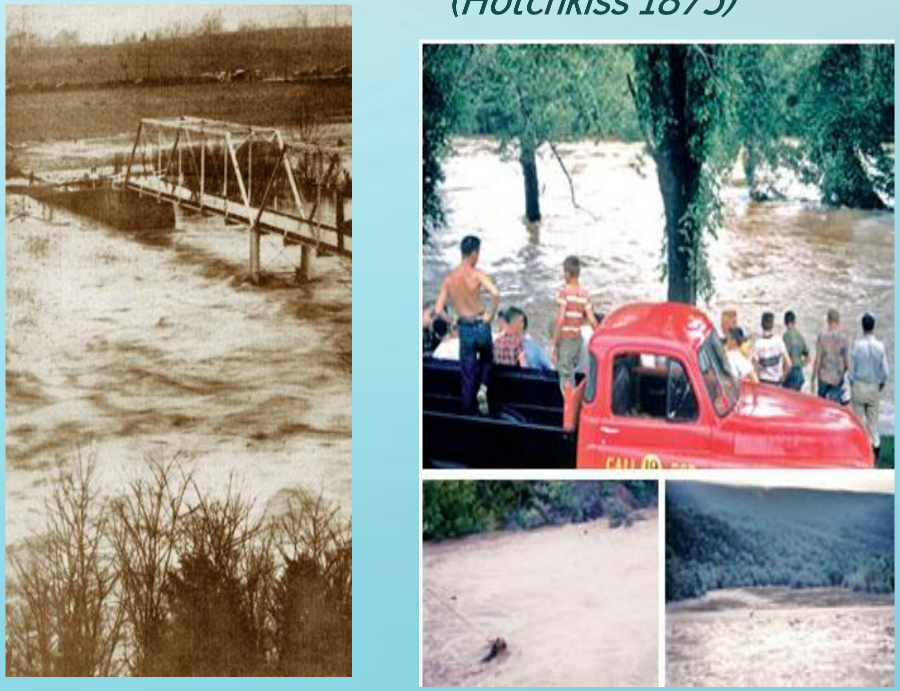


Burnshire: History

- Has had multiple names throughout the years
- In 1873, the Triplett family purchased the dam and converted the waterwheel to turbines as well as making the dam wall taller by 4ft.



(Hotchkiss 1875)



1936 and 1955 floods

Burnshire History and Dr. Harvey's Goals

- The dam began generating electricity for the town of Woodstock in 1903.
- Intermittent Operation
- Purchase by Dr. Lee Harvey and family
- Goals in purchasing the dam

Why is Burnshire unique?

- Not a traditional ROR
- Permanent Magnetic Generator
- Dam has been there for a very long time

Burnshire: Layout

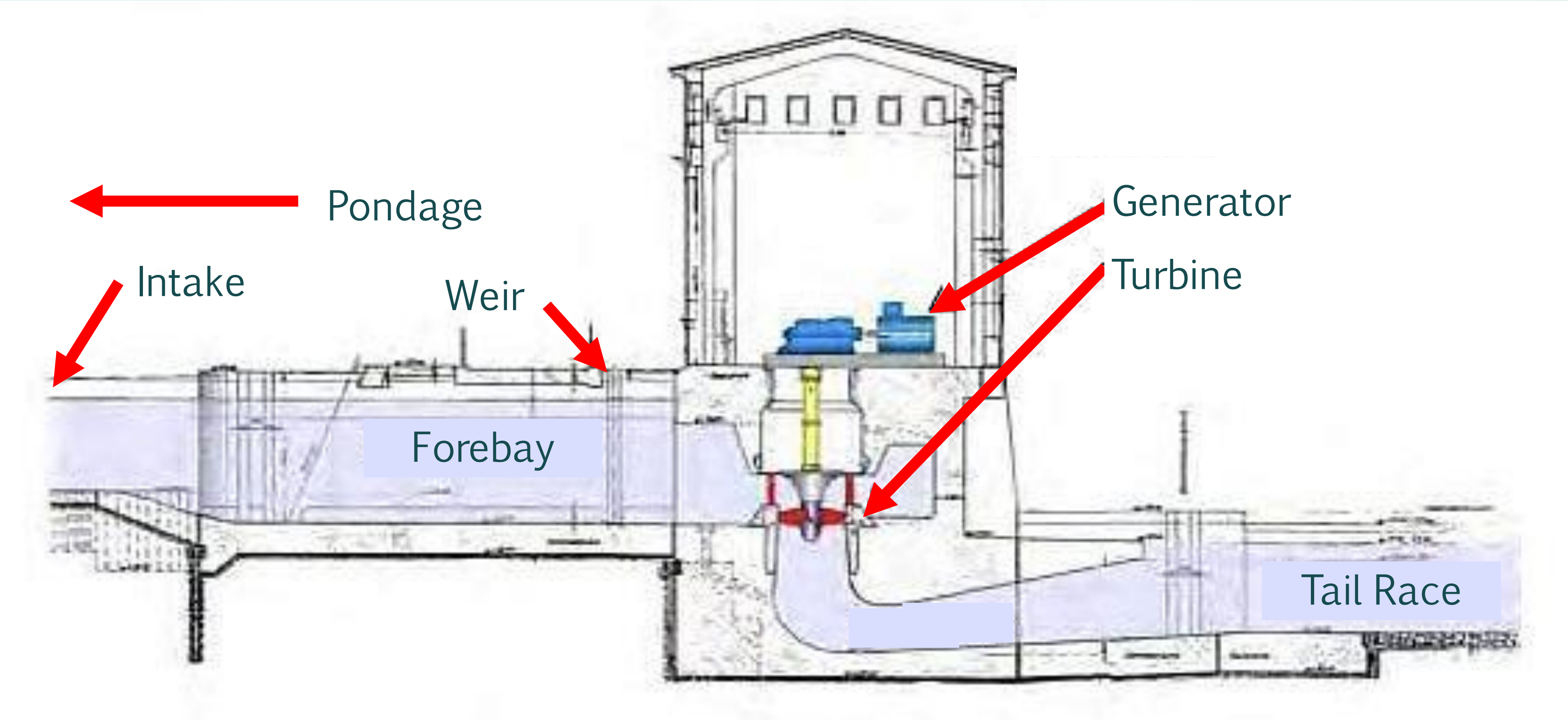
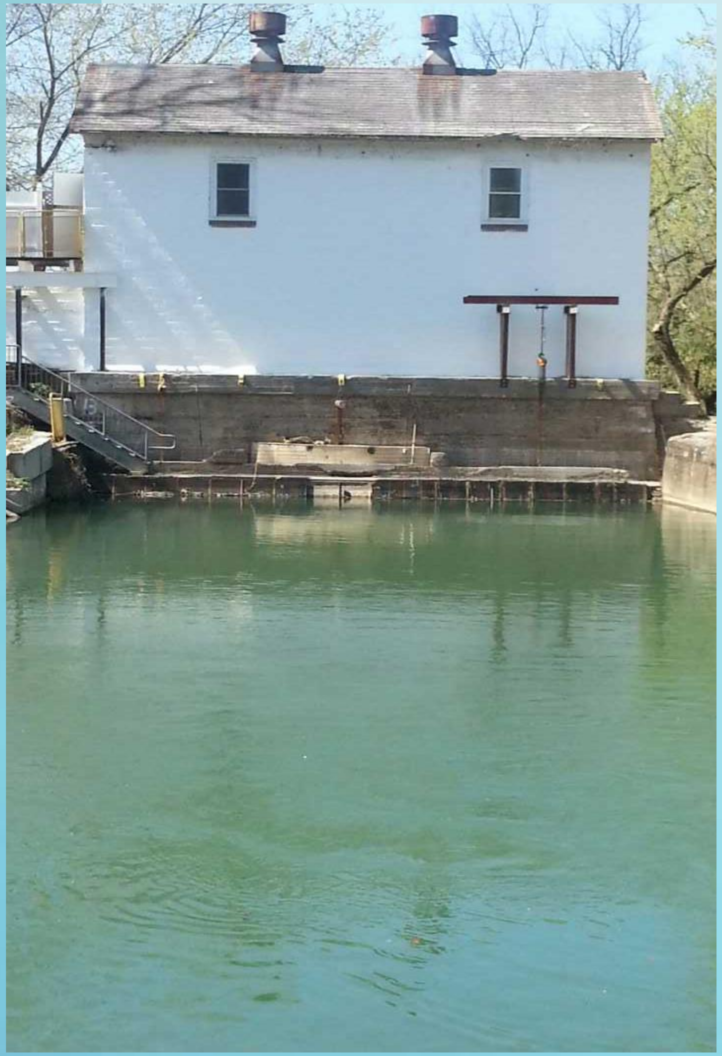


Image Source:http://www.wyomingrenewables.org/wyoming-small-hydropower-handbook/evaluating-resources/electromechanical-equipment1/

Views of the Burnishire Operation

Views, continued



Re-Statement of Problem

- Various questions surrounding our unique scenario
- What approach should be taken to solve the problem
- Methodology:
  - Similar Studies
  - Regulations
  - USGS Flow Data

Image Source: Dr. Lee Harvey

Unchartered Territory

- What other studies have been done?
- Lack of information
- New dams

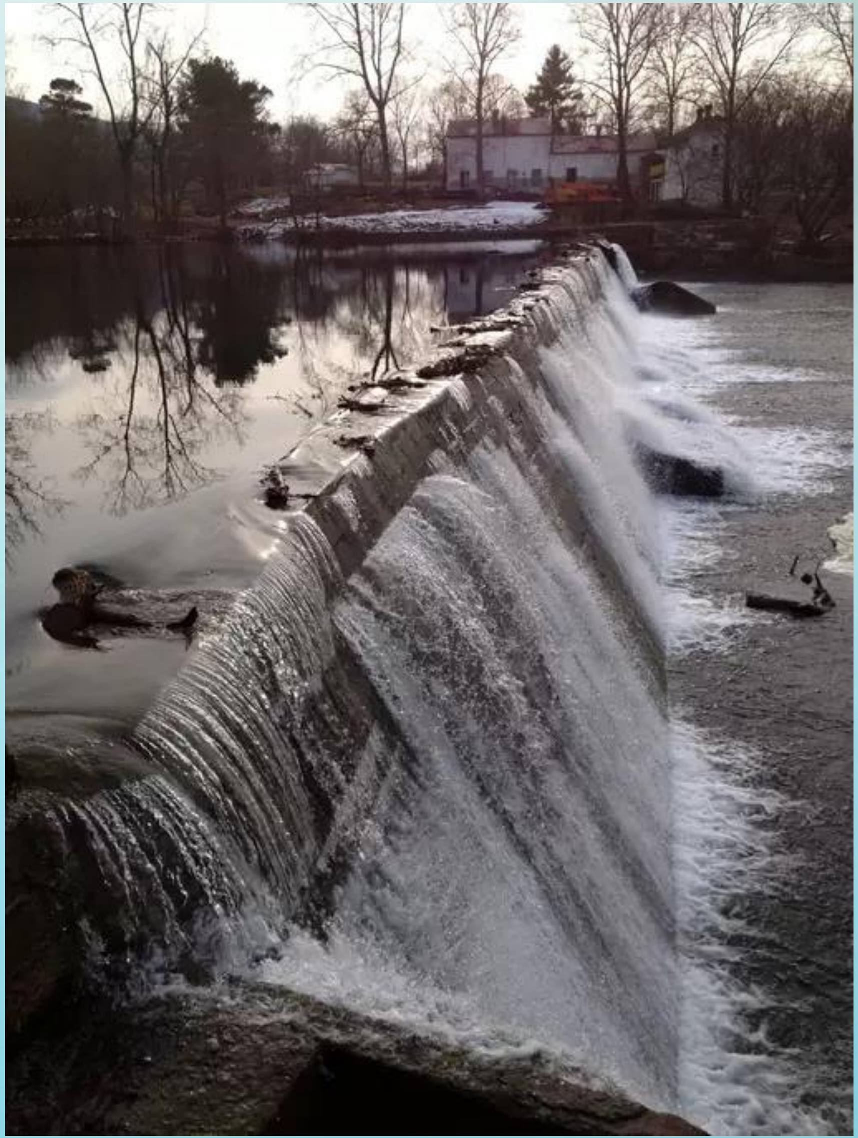
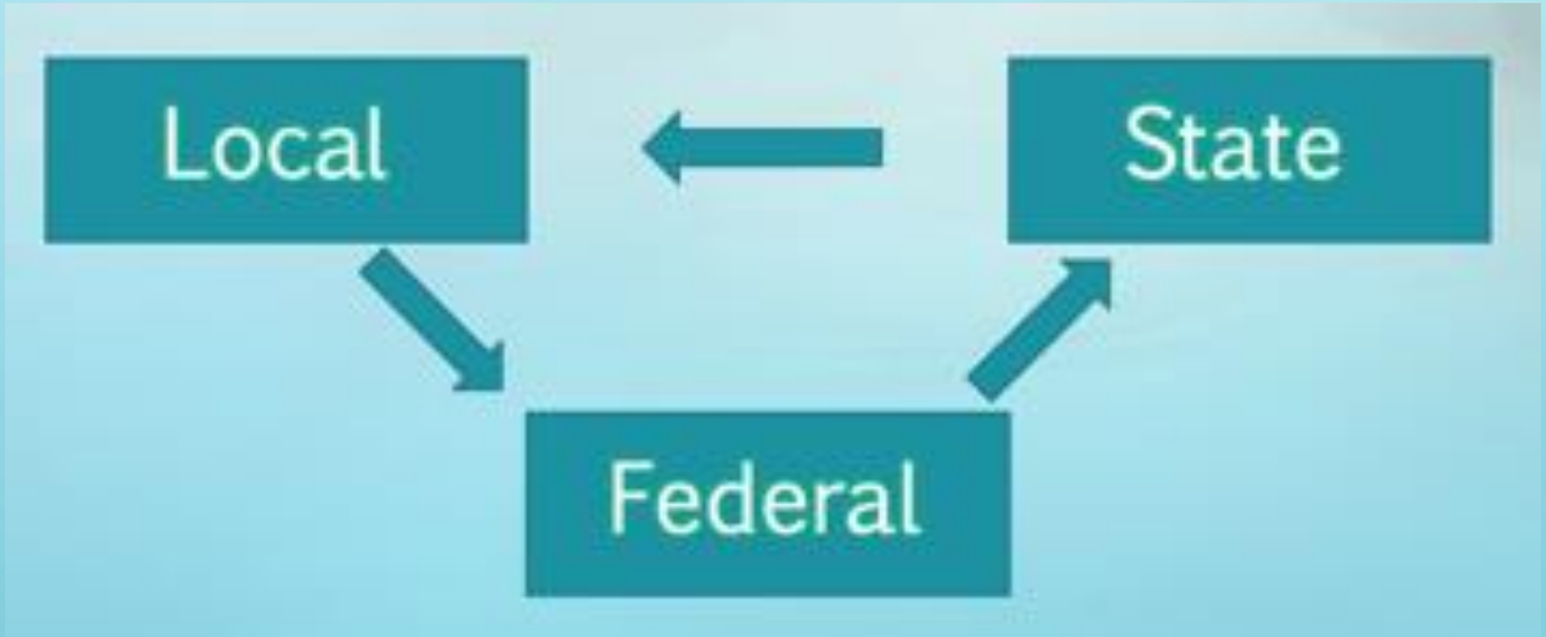


Image Source: https://a1.muscache.com/im/pictures/62842083/a87db4fa_original.jpg?aki_policy=x_large

Regulatory Studies

- What are the potential concerns?
- Biological Flow
- What are the environmental impacts?



Regulatory Environment: Federal

- FERC stated that the dam was out of its realm of regulation
- License Exemption

Image Source: https://pbs.twimg.com/profile_images/474183241797099520/altk2pR3.jpeg

Regulatory Environment: State

- Each of the organizations were contacted
- Ambiguities were revealed from each

Image Source: http://www.chesapeakebay.net/channel_files/18593/vadcr_qapp-agbmp_data_jan2015_2.pdf

Image Source: http://www.vocesverdes.org/in-the-news/627/virginia--5-upcoming-public-listening-sessions-regarding-cpp-proposal

Image Source: http://shootingcouncil.org/wp-content/uploads/2012/01/HuntFish-VA.png

Regulatory Environment: Local

- No ownership at the regional offices
- Redirected to the dam owner
- Age of dams
- Who is actually in charge?

DEQ Region Map

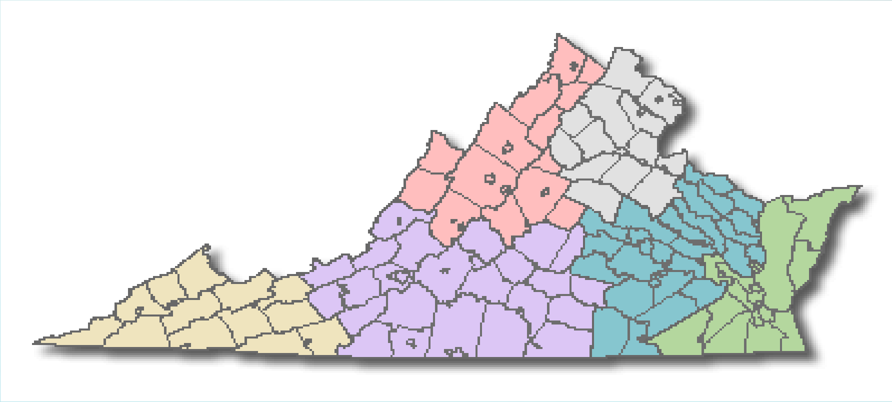


Image Source: http://www.deq.virginia.gov/Locations.aspx

DCR Region Map

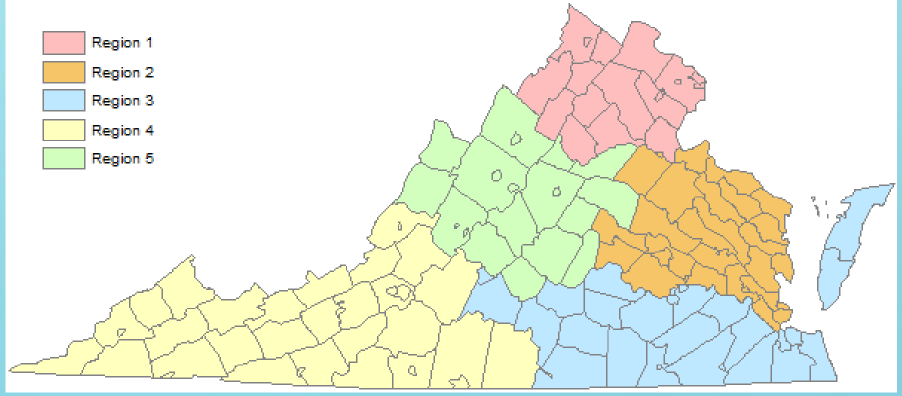


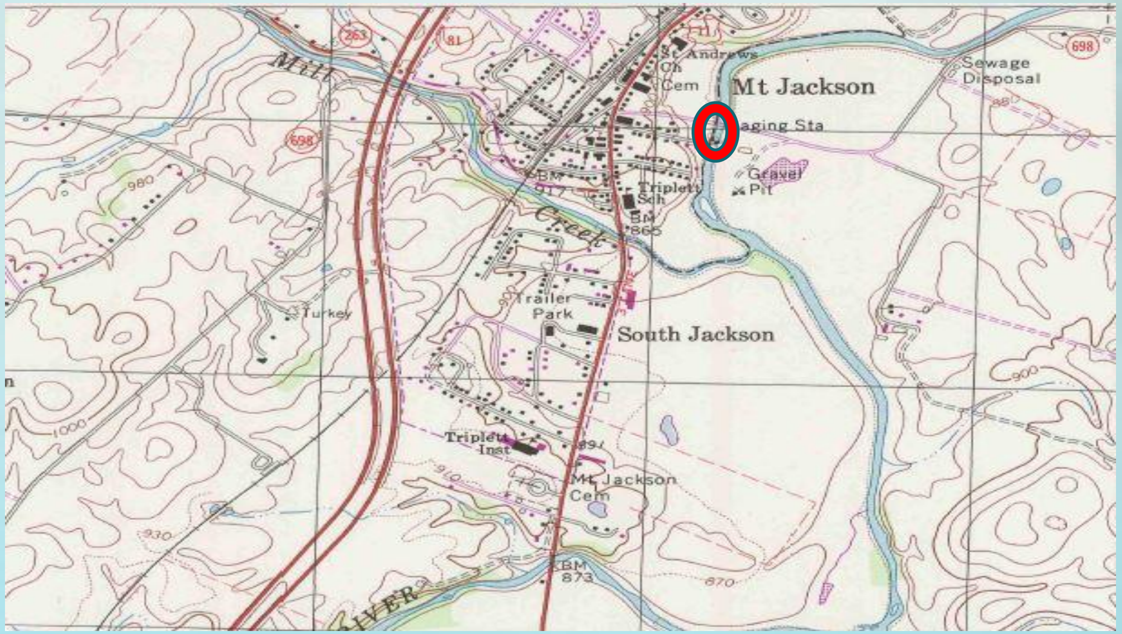
Image Source: http://www.dcr.virginia.gov/dam-safety-and-floodplains/dsfpmcontx

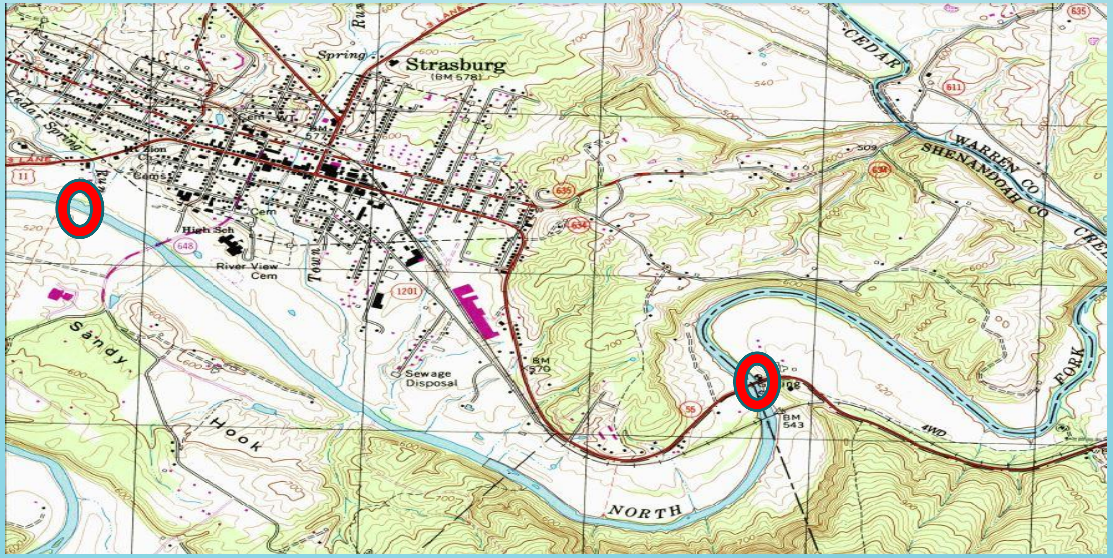
Flow Data

- Downloaded the data from the USGS online database

- From 1995-2015

Image Source: http://escweb.wr.usgs.gov/share/mooney/USGS_green.jpg





Map Image Source: Dr. Carole Nash

Strasburg Water Intake

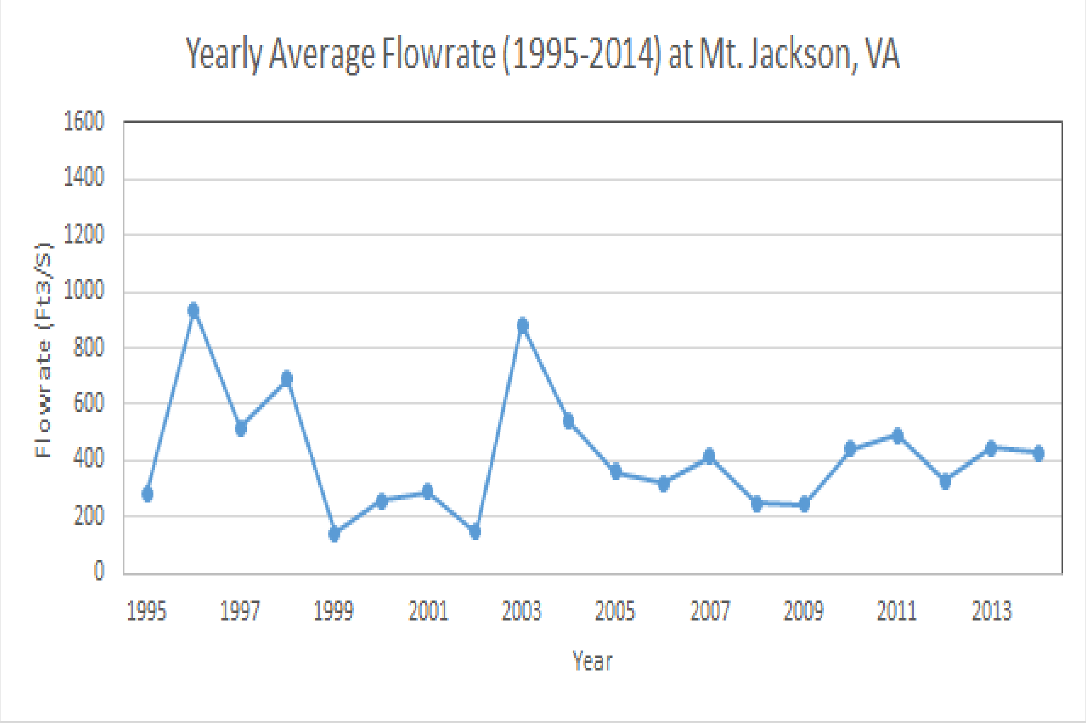
Image Source: http://www.panoramio.com/photo/88400739

Drought Response Measures (Va. DEQ)

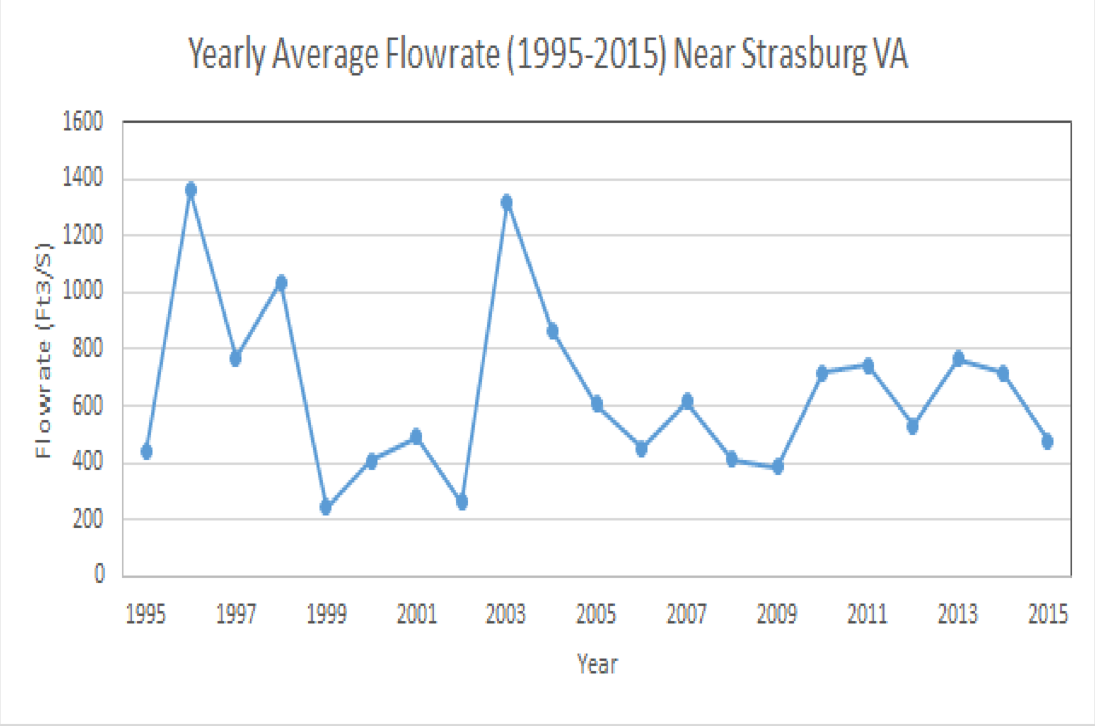
Low Water Event Classification	River Flow (cfs)
None	>175
Drought Watch	175 to 116
Drought Warning	115 to 91
Drought Emergency	<=90

Trends: Yearly

Mt. Jackson

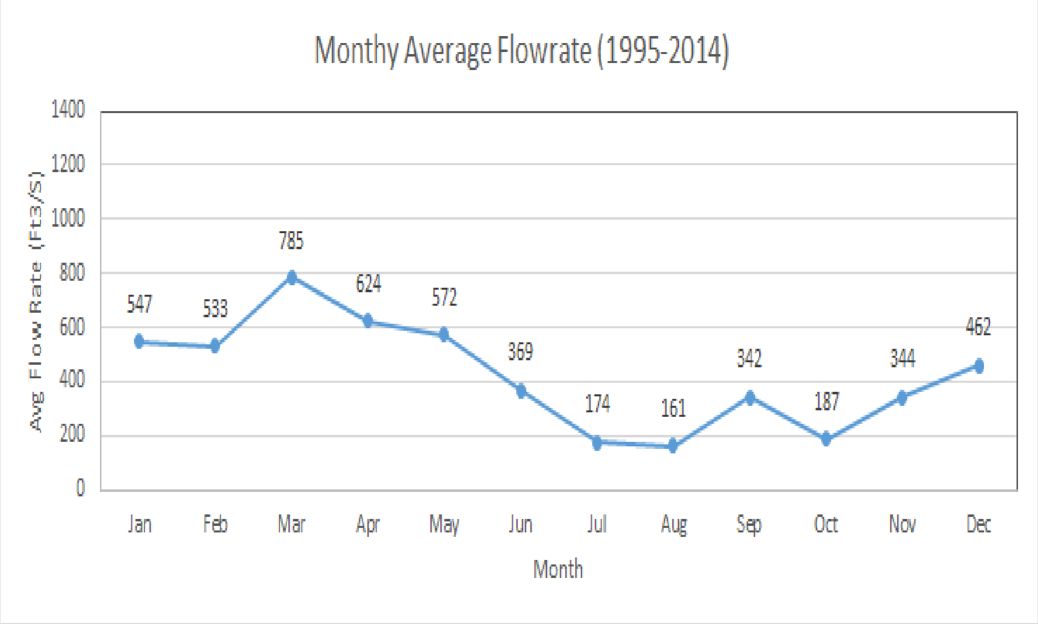


Strasburg

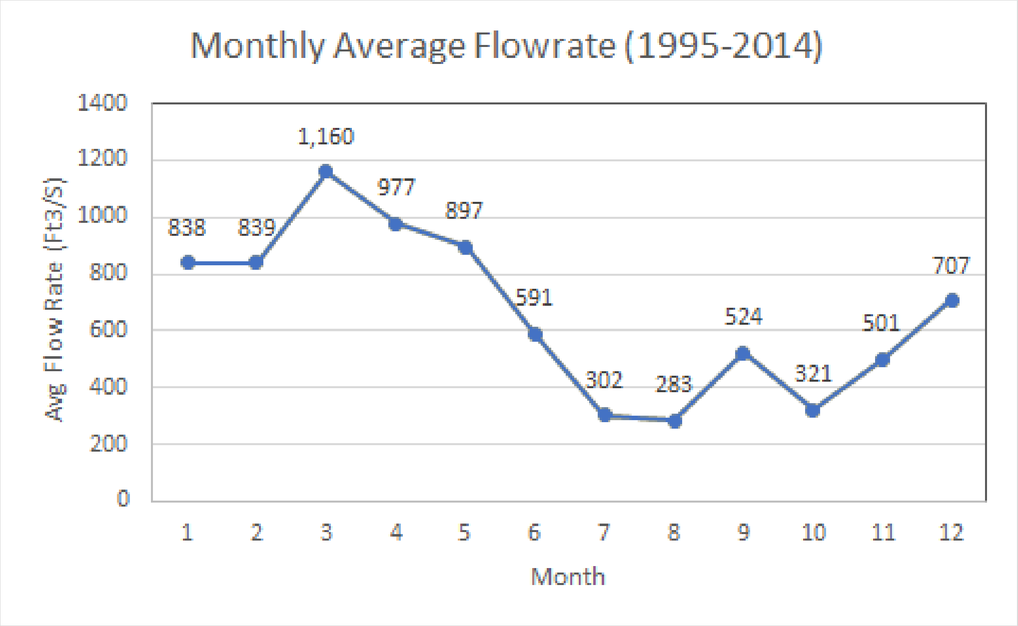


Trends: Monthly

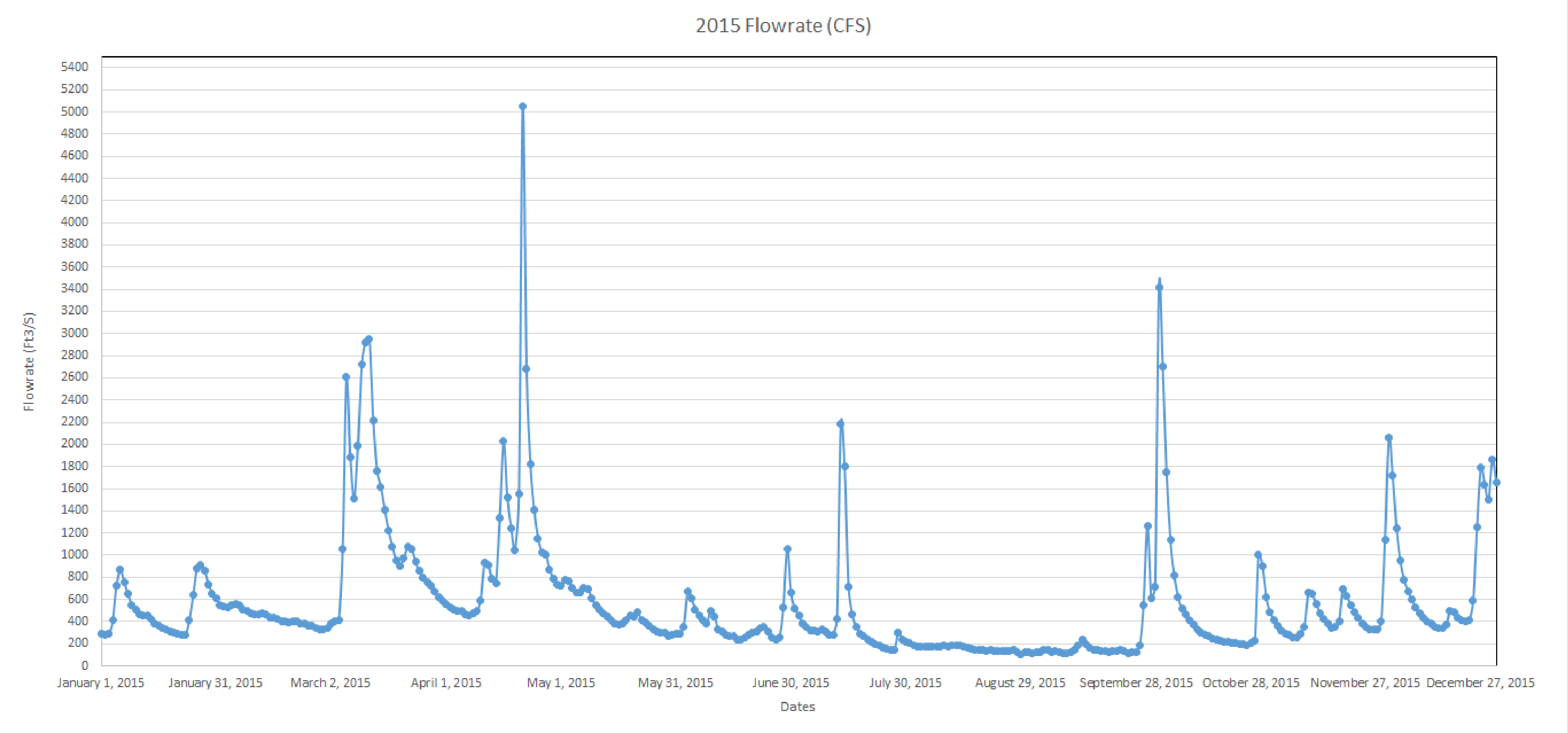
Mt. Jackson



Strasburg

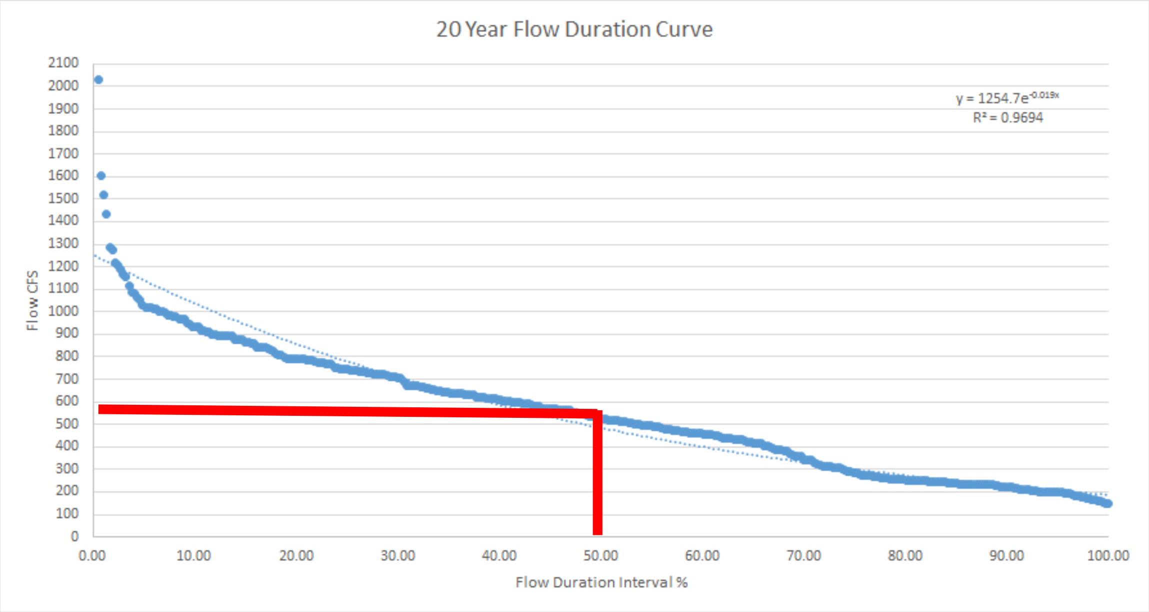


Trends: Strasburg Daily Avg. 2015

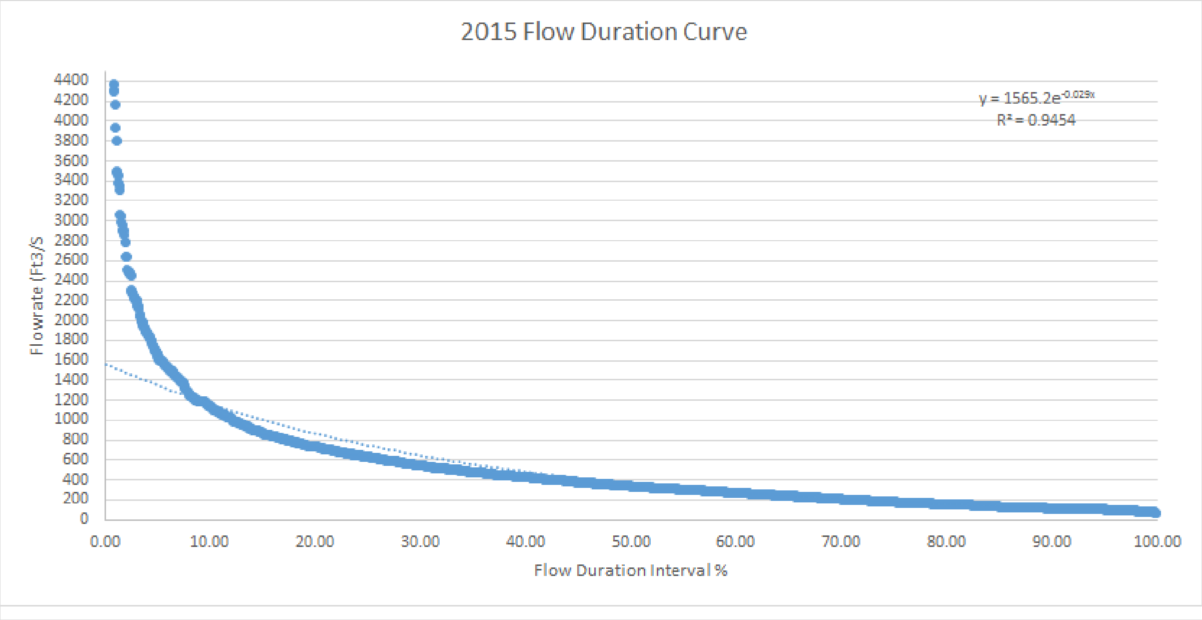


Flow Duration Curve

20 Year



2015



Appropriate Response, July-September 2015

July			August			September		
Date	CFS	Response	Date	CFS	Response	Date	CFS	Response
1	517	None	1	192	None	1	119	Watch
2	460	None	2	178	None	2	121	Watch
3	387	None	3	173	Watch	3	128	Watch
4	349	None	4	177	None	4	144	Watch
5	327	None	5	182	None	5	144	Watch
6	323	None	6	176	None	6	129	Watch
7	316	None	7	176	None	7	135	Watch
8	333	None	8	179	None	8	122	Watch
9	308	None	9	183	None	9	119	Watch
10	281	None	10	182	None	10	119	Watch
11	284	None	11	185	None	11	122	Watch
12	428	None	12	185	None	12	144	Watch
13	2,180	None	13	183	None	13	183	None
14	1,800	None	14	175	Watch	14	240	None
15	719	None	15	162	Watch	15	193	None
16	463	None	16	155	Watch	16	166	Watch
17	352	None	17	148	Watch	17	150	Watch
18	293	None	18	147	Watch	18	145	Watch
19	272	None	19	144	Watch	19	134	Watch
20	243	None	20	140	Watch	20	132	Watch
21	222	None	21	147	Watch	21	130	Watch
22	201	None	22	140	Watch	22	135	Watch
23	183	None	23	136	Watch	23	134	Watch
24	167	Watch	24	133	Watch	24	148	Watch
25	154	Watch	25	134	Watch	25	136	Watch
26	144	Watch	26	135	Watch	26	118	Watch
27	142	Watch	27	141	Watch	27	125	Watch
28	300	None	28	128	Watch	28	128	Watch
29	243	None	29	101	Warning	29	188	None
30	221	None	30	123	Watch	30	554	None
31	205	None	31	121	Watch			

Hypothesis

- If there is enough water in the pondage, during times of low flow this water might be utilized to supplement demand downstream.

Image Source: Dr. Carol Nash

River Work: Approach

- Basic plan to establish volume of water
- Two Measurements, depth upstream of the dam and cross sectional depths

Weir

Low water bridge where river depth is no greater than 3ft

River Work: Cross-Section

- Allows one to estimate typical bathymetry of the river and shape of the river bed

River work: Cross-Section

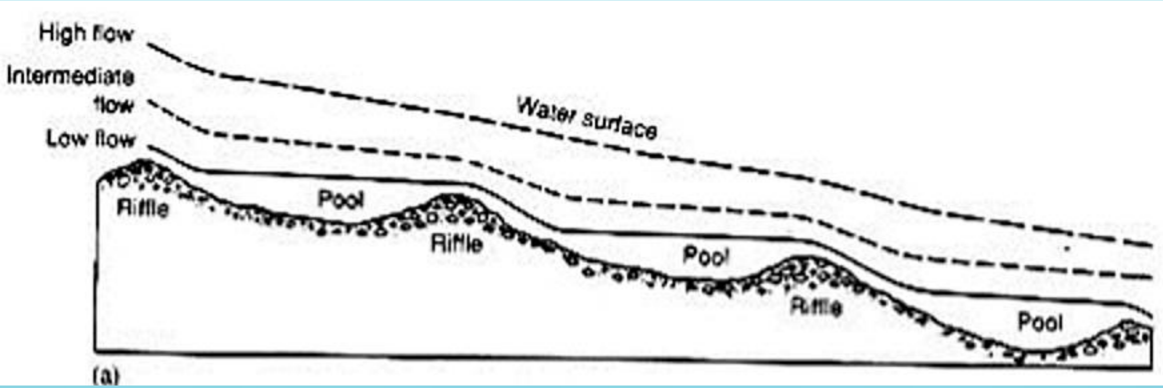
- Line drawn across the river and anchored
- Measurements taken using a grade rod
- All data was recorded and analyzed using Microsoft Excel
- Repeated three times

River Work: Upstream Depth Behind Dam

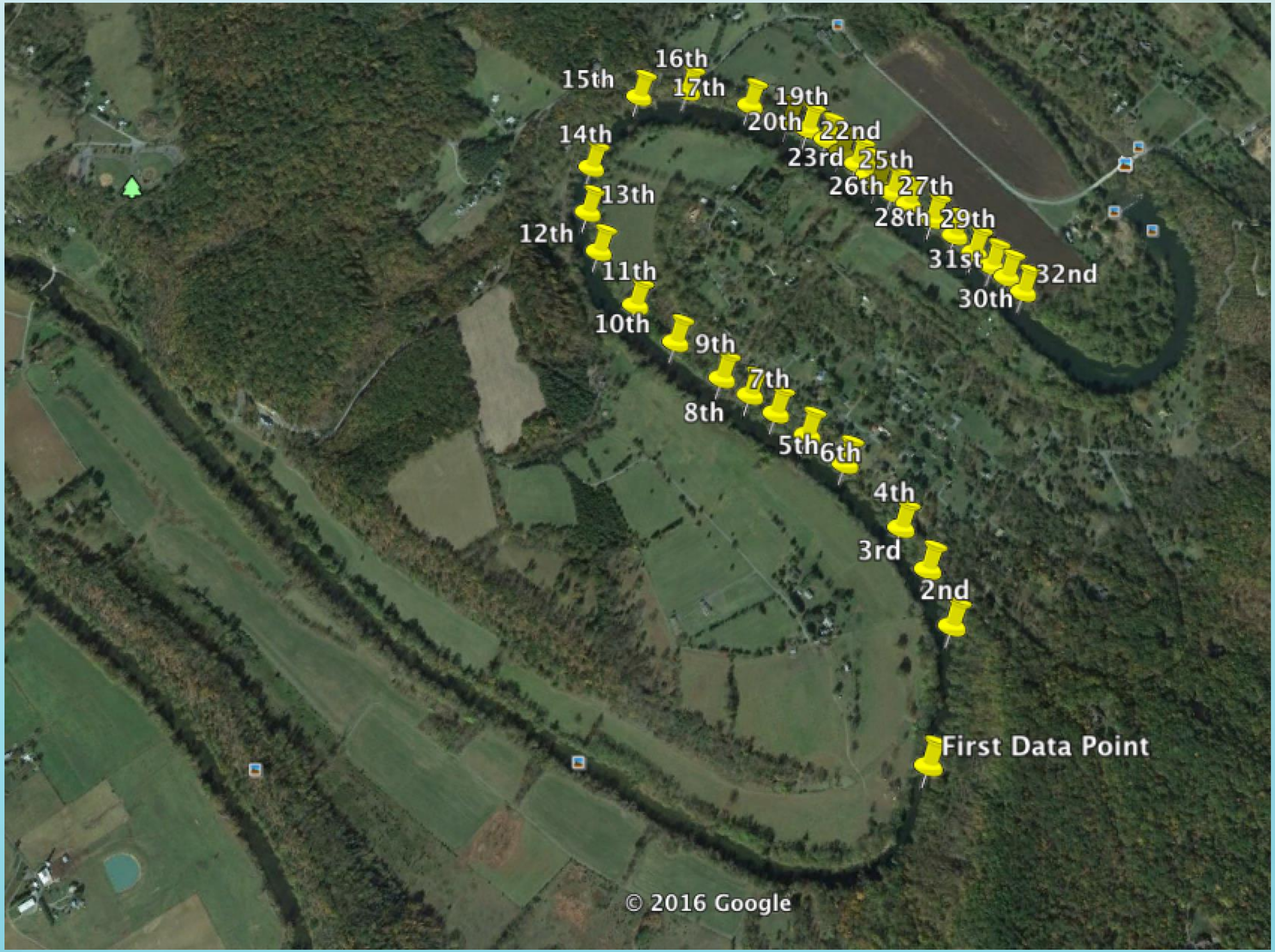
- Allows one to estimate the slope of the pondage upstream to where it resumes a riffle-pool sequence.

River work: Upstream Depth Behind Dam

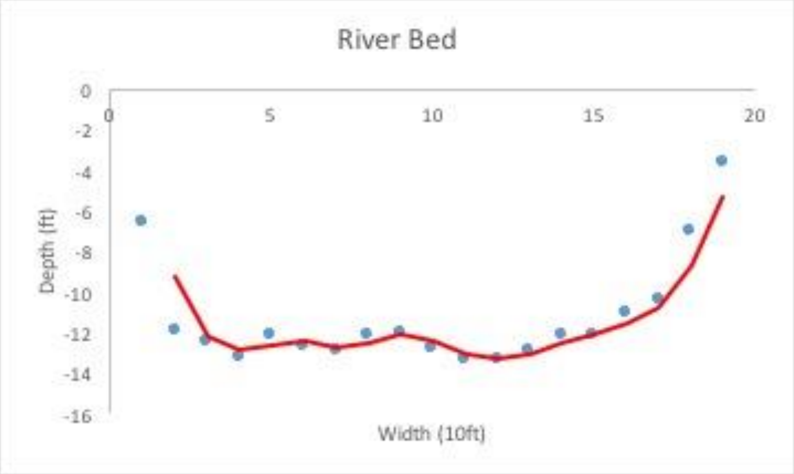
- Canoe was dropped at low water bridge
- Polarized sunglasses used to gauge when depth reached an excess of five feet
- Looking for pool/riffle attributes or widening of river
- Data was recorded from the first bend to the dam
- GPS Coordinates Plotted



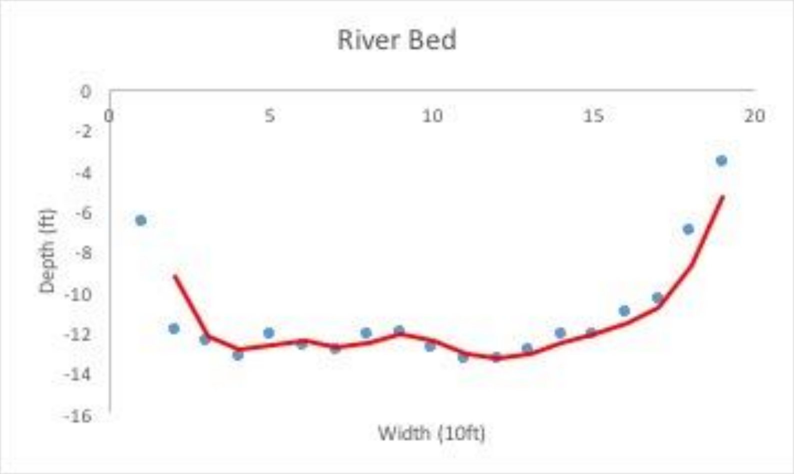
Measurements



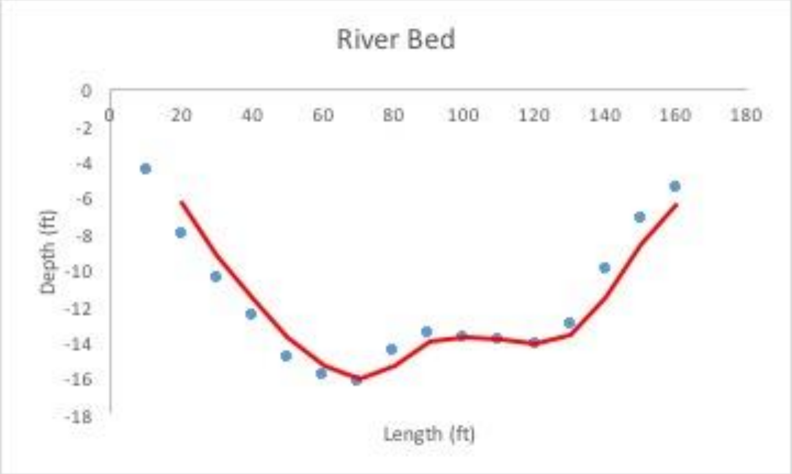
Data Analysis: Cross Section



Cross Section 1



Cross Section 2



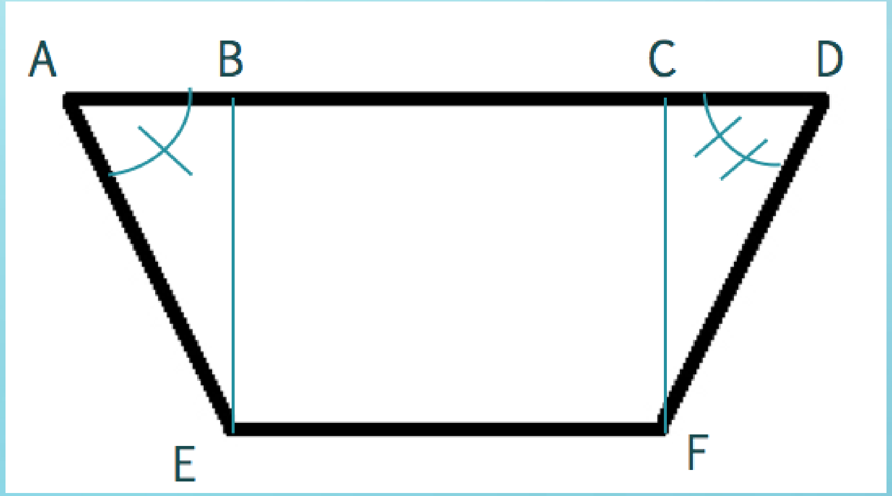
Cross Section 3

Data Analysis: Cross-Section

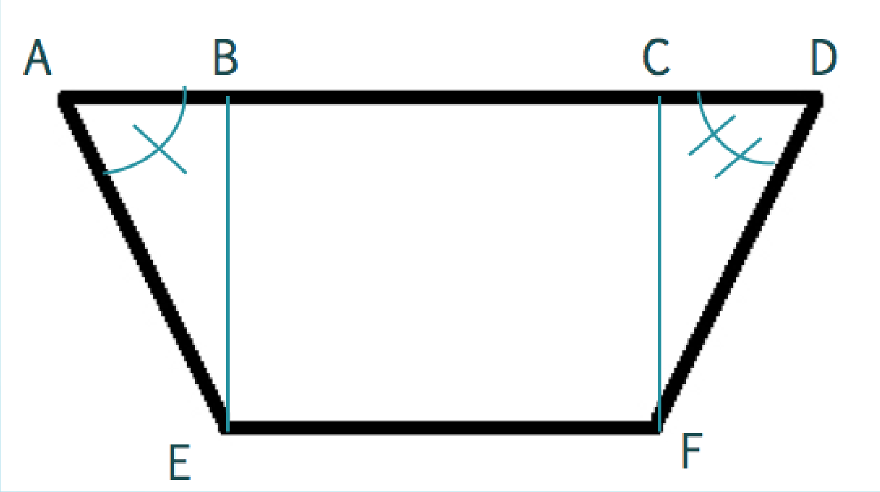
Power House Cross Section			
	CS1	CS2	CS3
Width at Max Depth (ft)	50	60	40
Total Width (ft)	210	190	160
Width at Max Depth/Total Width	0.23809524	0.31578947	0.25
Average	26.7961571	% of river	

Far Bank Cross Section			
	CS1	CS2	CS3
Width at Max Depth (ft)	40	50	50
Total Width (ft)	210	190	160
Width at Max Depth/Total Width	0.19047619	0.26315789	0.3125
Average	25.53780284	% of river	

The Cross-Sectional analysis indicates the average percentage of the width of the river that is not at maximum depth on either side due to the shallow sloping river bed.



Calculating Cross Sectional Area



$$Shallow\ Slope\ Floor\ Coefficient = {Width\ at\ Max\ Depth}/{Total\ River\ Width}$$

$$Average\ Shallow\ \ Slope\ Floor\ Coefficient * Width = Shallow\ Slope\ Floor\ Width\ (A\ to\ B\ or\ C\ to\ D)$$

$$Area\ of\ BCEF = BC * BE$$

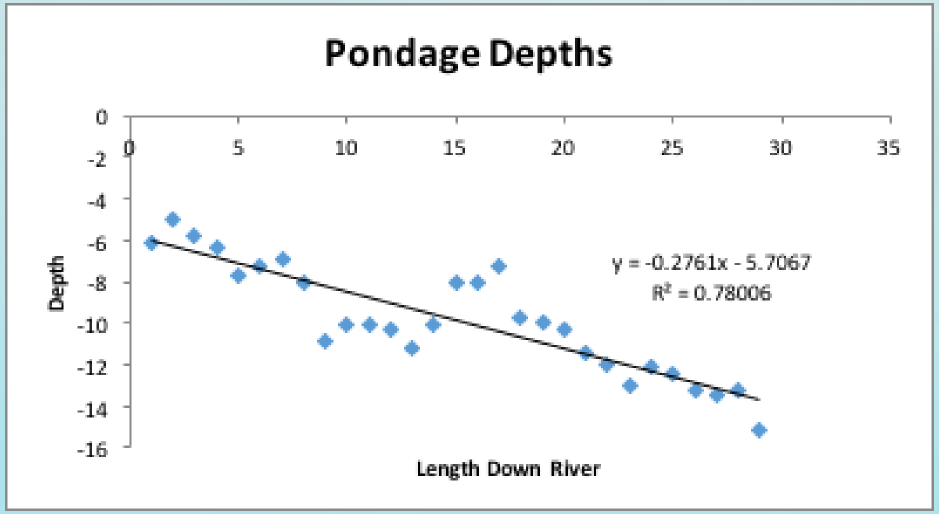
$$Area\ of\ ABE = \frac{1}{2}(AB * BE)$$

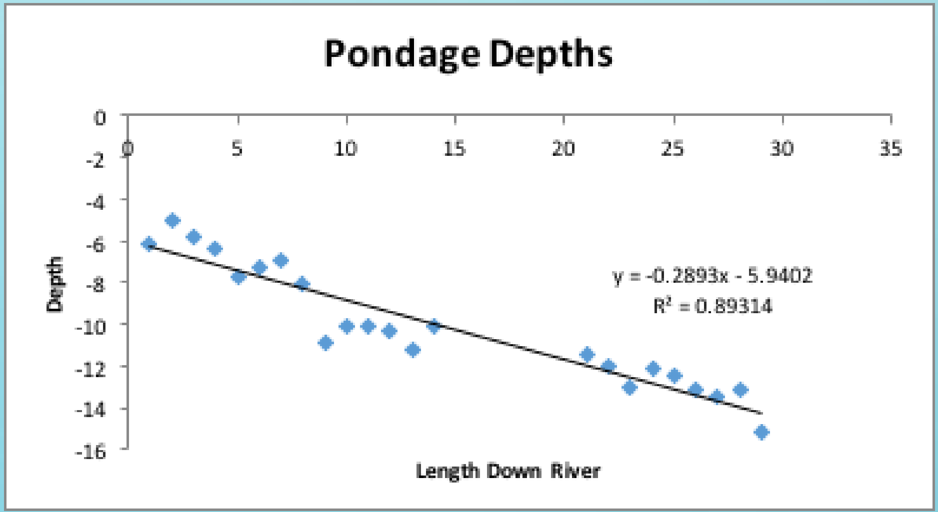
$$Area\ of\ CDF = \frac{1}{2}(CD * CF)$$

$$Cross\ Sectional\ Area = Area\ of\ ABE + Area\ of\ CDF + Area\ of\ BCEF$$

Data Analysis: Pondage Depths

Data Point	Depth
1	-6.1
2	-5
3	-5.8
4	-6.4
5	-7.7
6	-7.3
7	-6.9
8	-8.1
9	-10.9
10	-10.1
11	-10.1
12	-10.3
13	-11.2
14	-10.1
15	-8.1
16	-8.1
17	-7.3
18	-9.7
19	-10
20	-10.3
21	-11.4
22	-12
23	-13
24	-12.1
25	-12.5
26	-13.2
27	-13.5
28	-13.2
29	-15.2





Combining Data: Methodology

- Width at each data point was measured using Google Earth
- Cross-Sectional Area calculated at each of the depth measurements
- Area multiplied by distance to the next data point to produce third axis yielding the volume of one section
- Each of the sections were summed

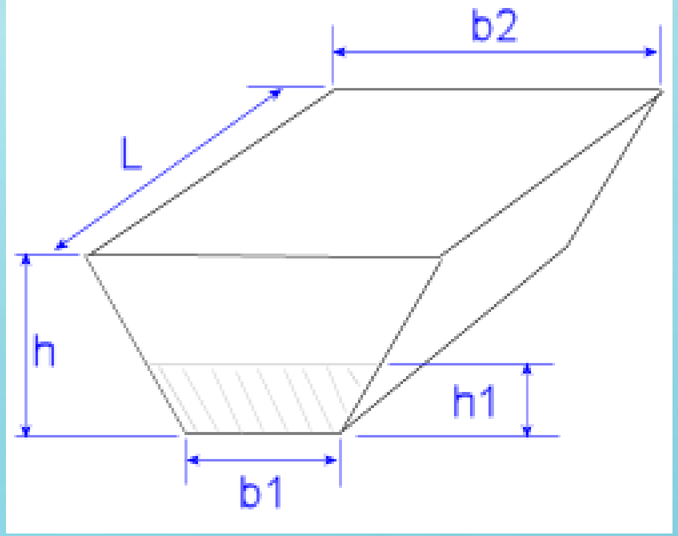


Image Source: http://www.onlineconversion.com/images/object_volume_trapezoid.png

Data Analysis: Total Volume

Marker No	Length (Ft)	Depth (Ft)	Width (Ft)	PH TRI Width (ft)	PH TRI Area (ft^2)	Volume (ft^3)	FS TRI Width (ft)	FS TRI Area (ft^2)	FS TRI Volume (Ft^3)	Center Width (ft)	Area (ft^2)	Volume (Ft^3)	Total Volume (Ft^3)
9	418	7.3	160	42.9	156.5	65412.6	40.9	149.1	62340.8	76.3	556.7	232717.0	360470.5
10	383	6.9	156	41.8	144.2	55235.1	39.8	137.4	52641.2	74.4	513.1	196508.6	304384.9
11	476	8.1	147	39.4	159.5	75936.7	37.5	152.0	72370.7	70.1	567.6	270158.3	418465.8
12	300	10.9	156	41.8	227.8	68346.3	39.8	217.1	65136.7	74.4	810.5	243154.0	376637.0
13	353	10.1	127	34.0	171.9	60665.6	32.4	163.8	57816.7	60.5	611.4	215828.5	334310.8
14	653	10.1	147	39.4	198.9	129895.6	37.5	189.6	123795.7	70.1	707.7	462126.6	715817.8
15	353	10.3	140	37.5	193.2	68199.7	35.8	184.1	64997.0	66.7	687.3	242632.5	375829.3
16	463	11.2	152	40.7	228.1	105605.2	38.8	217.4	100645.9	72.5	811.5	375709.1	581960.1
17	310	10.1	132	35.4	178.6	55373.2	33.7	170.2	52772.8	62.9	635.5	196999.9	305146.0
18	148	8.1	145	38.9	157.4	23289.3	37.0	150.0	22195.7	69.1	559.8	82856.0	128341.0
19	155	8.1	162	43.4	175.8	27250.5	41.4	167.6	25970.8	77.2	625.5	96948.4	150169.7
20	145	7.3	182	48.8	178.0	25811.0	46.5	169.6	24598.9	86.8	633.3	91827.2	142237.1
21	137	9.7	195	52.3	253.4	34719.2	49.8	241.5	33088.8	92.9	901.6	123519.6	191327.6
22	117	10	187	50.1	250.5	29313.7	47.8	238.8	27937.1	89.1	891.4	104288.5	161539.3
23	92	10.3	190	50.9	262.2	24122.4	48.5	249.9	22989.6	90.6	932.8	85819.8	132931.9
24	128	11.4	193	51.7	294.8	37732.4	49.3	280.9	35960.5	92.0	1048.7	134239.8	207932.7
25	140	12	177	47.4	284.6	39840.5	45.2	271.2	37969.6	84.4	1012.4	141739.7	219549.9
26	206	13	180	48.2	313.5	64584.1	46.0	298.8	61551.2	85.8	1115.4	229769.4	355904.7
27	201	12.1	181	48.5	293.4	58979.7	46.2	279.7	56210.0	86.3	1043.9	209830.7	325020.4
28	187	12.5	168	45.0	281.4	52614.3	42.9	268.1	50143.5	80.1	1001.0	187184.5	289942.3
29	158	13.1	170	45.6	298.4	47143.3	43.4	284.4	44929.4	81.0	1061.5	167720.6	259793.3
30	135	13.1	180	48.2	315.9	42650.1	46.0	301.1	40647.2	85.8	1124.0	151735.3	235032.7
31	167	13.1	175	46.9	307.2	51294.2	44.7	292.7	48885.4	83.4	1092.7	182488.2	282667.9
32	250	13.1	168	45.0	294.9	73716.2	42.9	281.0	70254.5	80.1	1049.0	262258.6	406229.3
33	317	13.1	180	48.2	315.9	100148.8	46.0	301.1	95445.8	85.8	1124.0	356297.0	551891.5
34	335	13.1	223	59.8	391.4	131118.4	56.9	373.0	124961.0	106.3	1392.5	466476.8	722556.1
35	290	13.1	212	56.8	372.1	107906.5	54.1	354.6	102839.2	101.1	1323.8	383896.6	594642.3
36	282	13.1	136	36.4	238.7	67313.4	34.7	227.5	64152.4	64.8	849.2	239479.5	370945.4
37	425	13.1	152	40.7	266.8	113382.6	38.8	254.3	108058.1	72.5	949.1	403378.6	624819.3
38	328	13.1	144	38.6	252.7	82899.2	36.8	240.9	79006.2	68.6	899.2	294928.5	456833.8
39	296	13.1	205	54.9	359.8	106502.4	52.4	342.9	101501.0	97.7	1280.1	378901.2	586904.6

Findings

- Total Volume of Water ~11,000,000 ft^3 or ~83,000,000 gallons
- What questions should be asked?
- How can this data be utilized?
- Consideration of depth of dam inlet

Image Source: http://shenandoahcountyva.us/economic-development/utilities/

Image Source: http://shenandoahcountyva.us/economic-development/utilities/

Total Volume With Respect to Relative Depth

Marker No	Length (Ft)	Depth (Ft)	Width (Ft)	PH TRI Width (ft)	PH TRI Area (ft^2)	Volume (ft^3)	FS TRI Width (ft)	FS TRI Area (ft^2)	FS TRI Volume (Ft^3)	Center Width (ft)	Area (ft^2)	Volume (Ft^3)	Total Volume (Ft^3)
9	418	5	160	42.9	107.2	44803.2	40.9	102.2	42699.2	76.3	381.3	159395.2	246897.6
10	383	5	156	41.8	104.5	40025.4	39.8	99.6	38145.8	74.4	371.8	142397.5	220568.8
11	476	5	147	39.4	98.5	46874.5	37.5	93.9	44673.3	70.1	350.3	166764.4	258312.2
12	300	5	156	41.8	104.5	31351.5	39.8	99.6	29879.2	74.4	371.8	111538.5	172769.3
13	353	5	127	34.0	85.1	30032.5	32.4	81.1	28622.1	60.5	302.7	106845.8	165500.4
14	653	5	147	39.4	98.5	64304.7	37.5	93.9	61285.0	70.1	350.3	228775.5	354365.3
15	353	5	140	37.5	93.8	33106.7	35.8	89.4	31552.0	66.7	333.7	117782.8	182441.4
16	463	5	152	40.7	101.8	47145.2	38.8	97.0	44931.2	72.5	362.3	167727.3	259803.6
17	310	5	132	35.4	88.4	27412.5	33.7	84.3	26125.2	62.9	314.6	97524.7	151062.4
18	148	5	145	38.9	97.1	14376.1	37.0	92.6	13701.0	69.1	345.6	51145.7	79222.8
19	155	5	162	43.4	108.5	16821.3	41.4	103.4	16031.4	77.2	386.1	59844.7	92697.4
20	145	5	182	48.8	121.9	17678.8	46.5	116.2	16848.6	86.8	433.8	62895.3	97422.7
21	137	5	195	52.3	130.6	17896.5	49.8	124.5	17056.1	92.9	464.7	63669.9	98622.5
22	117	5	187	50.1	125.3	14656.8	47.8	119.4	13968.5	89.1	445.7	52144.3	80769.6
23	92	5	190	50.9	127.3	11709.9	48.5	121.3	11160.0	90.6	452.8	41660.1	64530.1
24	128	5	193	51.7	129.3	16549.3	49.3	123.2	15772.1	92.0	460.0	58877.1	91198.5
25	140	5	177	47.4	118.6	16600.2	45.2	113.0	15820.7	84.4	421.8	59058.2	91479.1
26	206	5	180	48.2	120.6	24840.0	46.0	114.9	23673.5	85.8	429.0	88372.8	136886.4
27	201	5	181	48.5	121.3	24371.8	46.2	115.6	23227.3	86.3	431.4	86706.9	134306.0
28	187	5	168	45.0	112.5	21045.7	42.9	107.3	20057.4	80.1	400.4	74873.8	115976.9
29	158	5	170	45.6	113.9	17993.6	43.4	108.5	17148.6	81.0	405.2	64015.5	99157.7
30	135	5	180	48.2	120.6	16278.7	46.0	114.9	15514.2	85.8	429.0	57914.2	89707.1
31	167	5	175	46.9	117.2	19577.9	44.7	111.7	18658.6	83.4	417.1	69652.0	107888.5
32	250	5	168	45.0	112.5	28136.0	42.9	107.3	26814.7	80.1	400.4	100098.7	155049.3
33	317	5	180	48.2	120.6	38224.7	46.0	114.9	36429.7	85.8	429.0	135991.2	210645.6
34	335	5	223	59.8	149.4	50045.2	56.9	142.4	47695.0	106.3	531.5	178044.6	275784.8
35	290	5	212	56.8	142.0	41185.7	54.1	135.4	39251.6	101.1	505.3	146525.4	226962.7
36	282	5	136	36.4	91.1	25692.2	34.7	86.8	24485.6	64.8	324.1	91404.4	141582.2
37	425	5	152	40.7	101.8	43275.8	38.8	97.0	41243.6	72.5	362.3	153961.3	238480.7
38	328	5	144	38.6	96.5	31640.9	36.8	91.9	30155.0	68.6	343.2	112568.1	174364.1
39	296	5	205	54.9	137.3	40649.8	52.4	130.9	38740.8	97.7	488.6	144618.8	224009.4

Findings

- Total Volume of Water ~5,000,000 ft^3 or ~37,000,000 gallons
- What questions should be asked?
- How can this data be utilized?

Conclusions

Water Systems

Jurisdiction	Source	Maximum Daily Capacity	Average Daily Use	Storage
Woodstock	River	1,800,000 gpd	500,000 gal.	2,700,000 gal. (0)
New Market	Wells	1,000,000 gpd	545,000 gal.	500,000 gal. (0)
Strasburg	River & Reservoirs	3,369,000 gpd	750,000 gal.	3,300,000 gal. (0)

Image Source: http://shenandoahcountyva.us/economic-development/utilities/

Sewer Systems

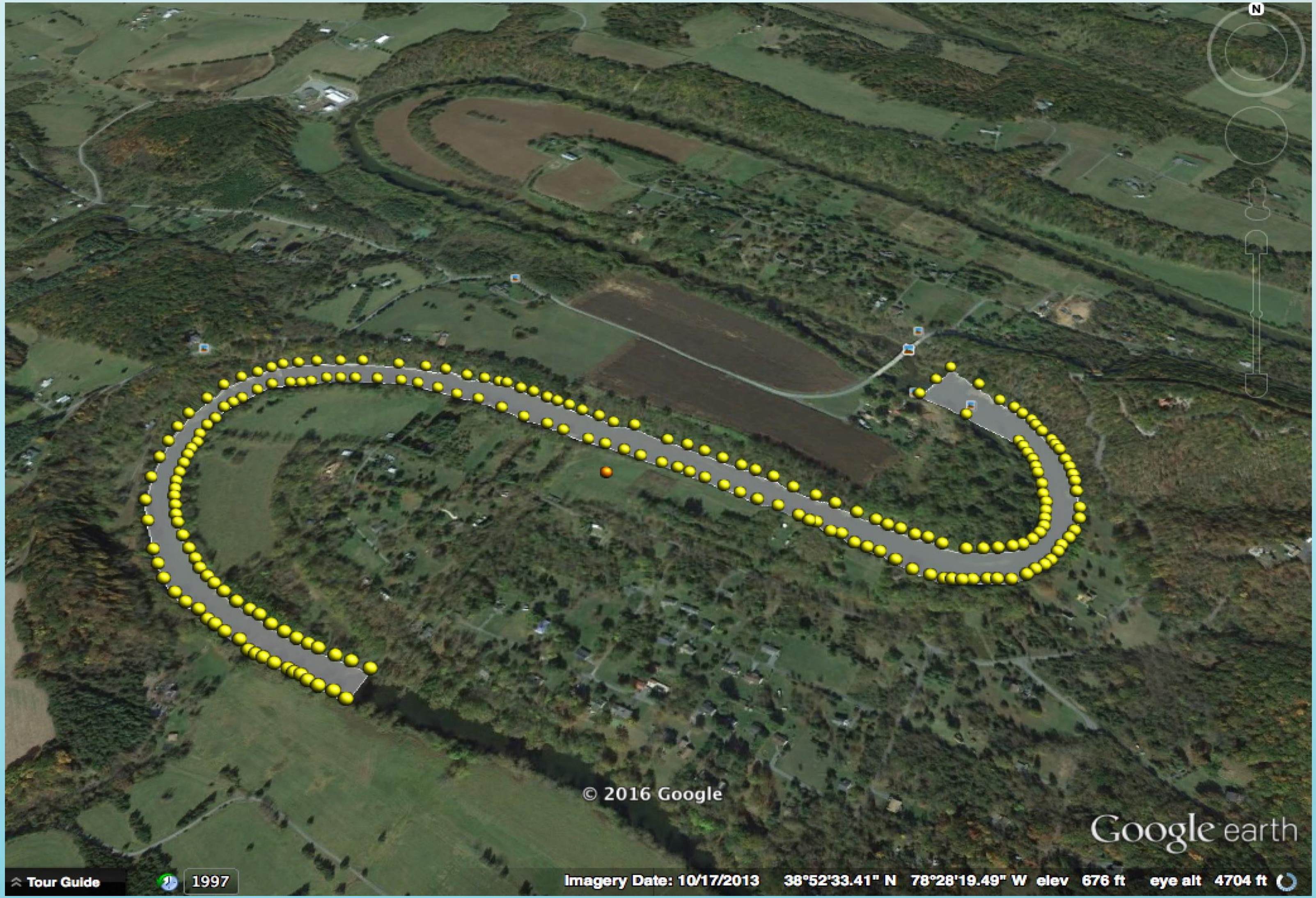
Jurisdiction	Maximum Daily Capacity	Average Daily Use	Treatment
Woodstock	2,000,000 gpd	500,000 gpd	Secondary
New Market	1,000,000 gpd	400,000 gpd	Secondary
Strasburg	975,000 gpd	850,000 gpd	Secondary/ Biological Activation

Image Source: http://shenandoahcountyva.us/economic-development/utilities/

Future Investigations

- What agencies would monitor the water flow?
- Damage from bank deterioration and sedimentation
- Correlation between the flow and depth of the river at different times of the year?
- Monitoring the pondage volume and relative depth in drought and high flow conditions
- Chapman Dam involvement for serial releases
- Applicability to other ROR dams

Pondage Polygon



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Thank You!

We will now be taking questions