Geneva Dam

Design of a Steep, Temporary, Riprap Ramp

ILLINOIS DEPARTMENT OF NATURAL RESOURCES

PBS&J

A Run-of-River Dam Analysis for Geneva Dam

Credit to:

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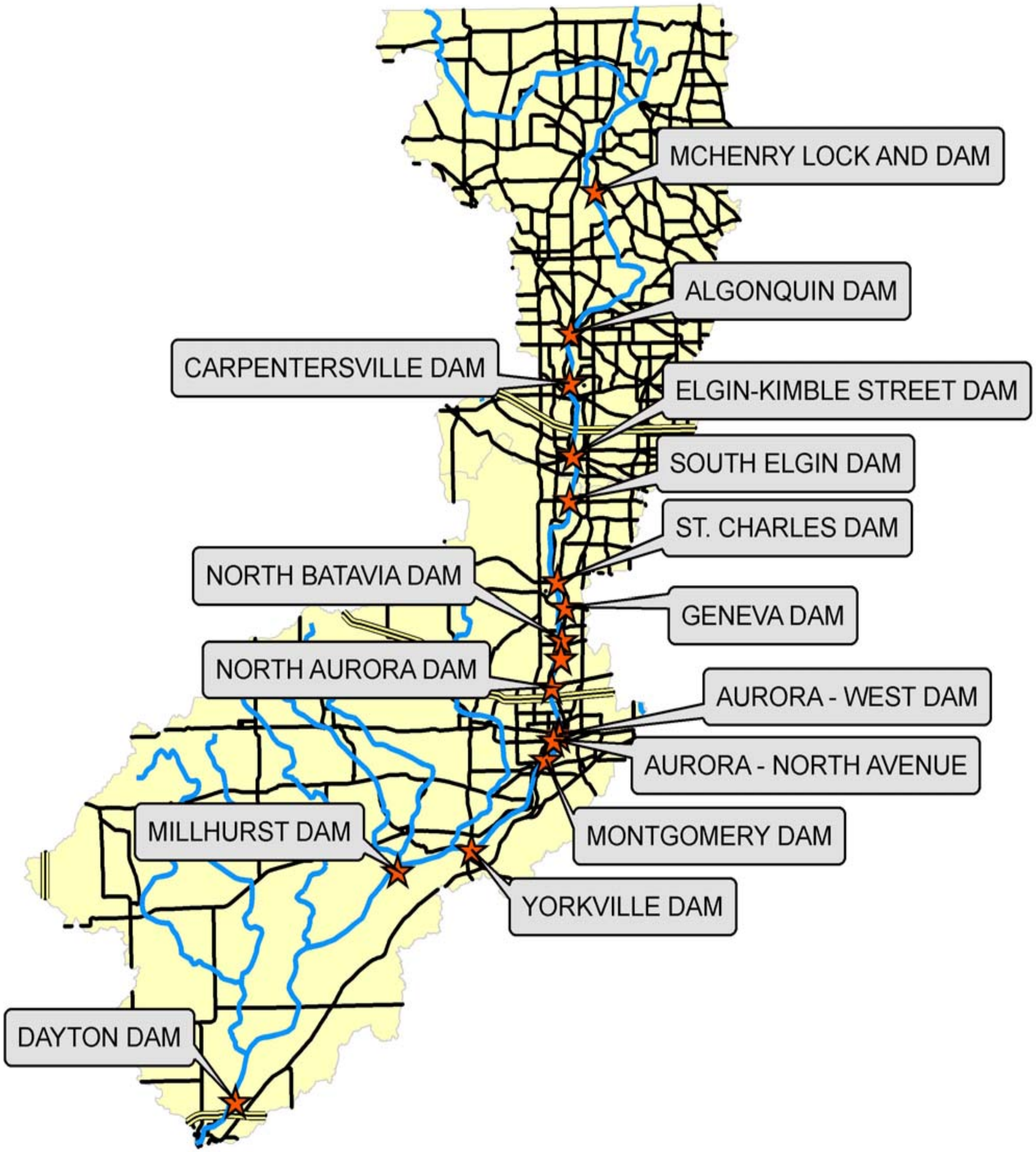
Presentation Purpose –

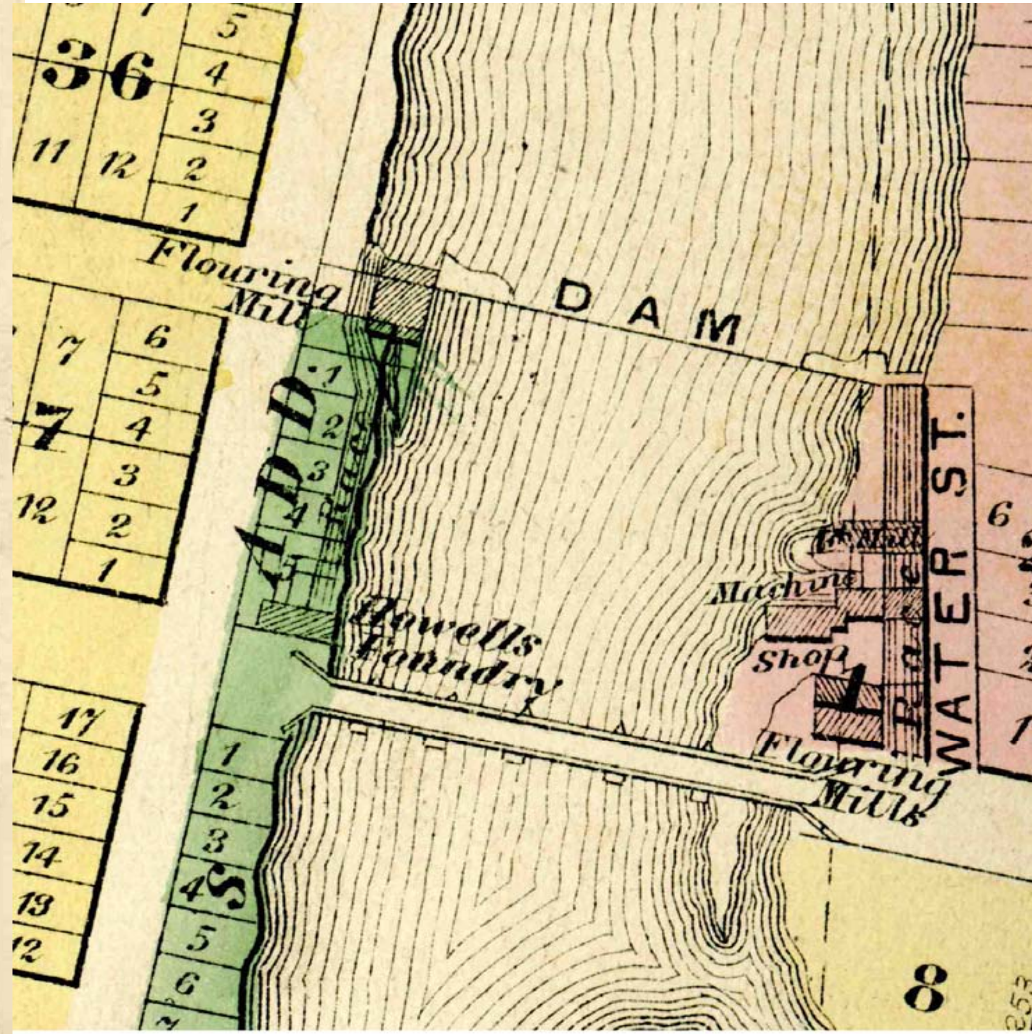
- History of the Geneva Dam
- Problems with the dam
- Potential Solutions
- Modeling Hydraulic Characteristics of the Dam
- Rock ramp sizing

Fox River Dams



History of Geneva Dam
Built in 1837 for Sterling Sawmill

Several mills operational along 2 raceways by the 1870's



1871 Atlas Map of Geneva:

Popular Swimming Hole

And Popular Fishing Hole

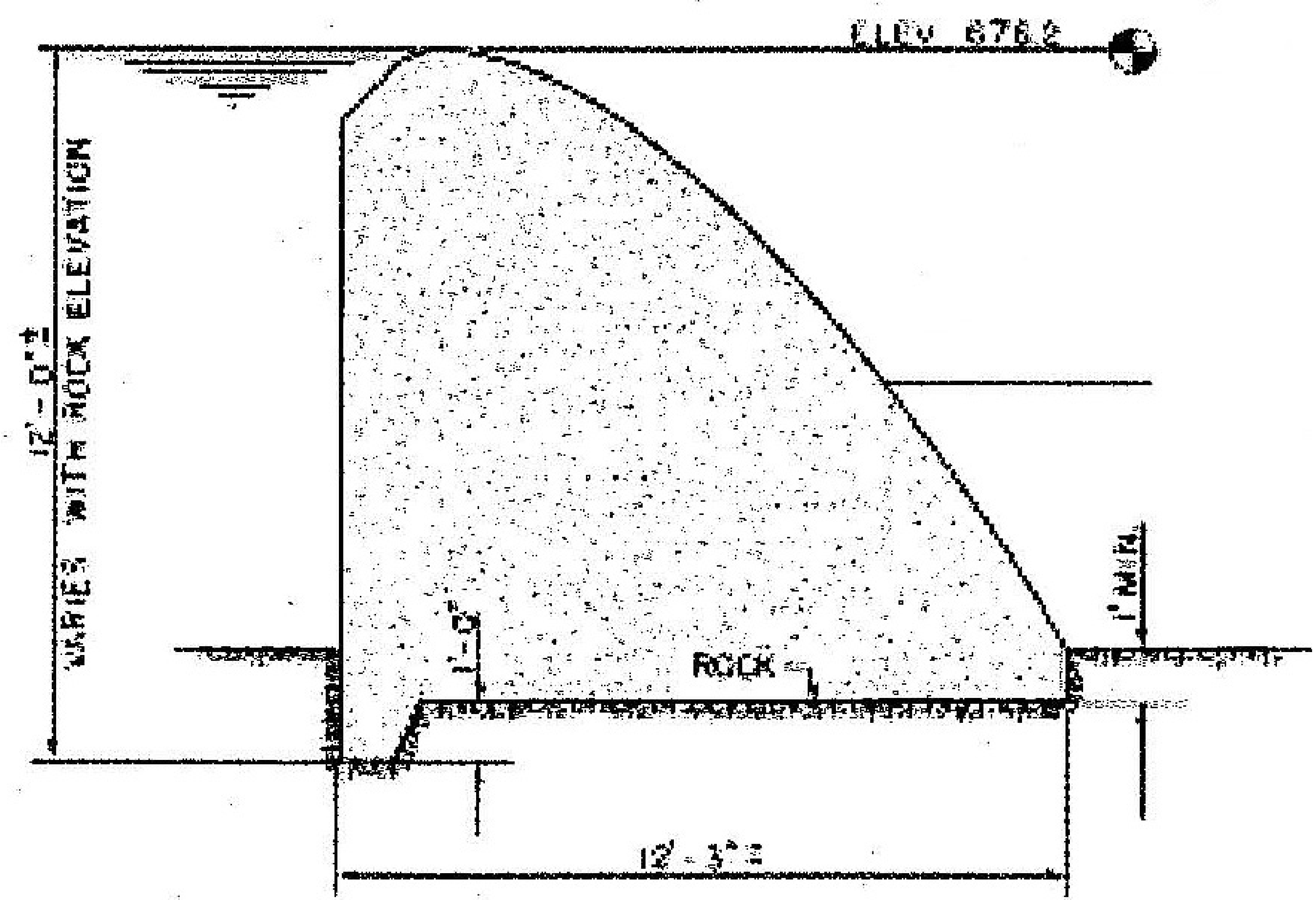
1950's: Problems with the dam


GENEVA, ILLINOIS, THURSDAY, OCTOBER 23, 1952

Chamber of Commerce Studies Dam Problem

1960 – New Ogee Spillway Dam

September 22 , 1960



ELEV
12'-0"±
VARIES WITH ROCK ELEVATION
ROCK
12'-3"±

Geneva Dam Basic information

- **Type - ogee**
- **Material - concrete**
- **Weir Length - 441 ft**
- **Height - 13 ft**
- **Spillway crest elevation - 675.40 ft**
- **Length of pool - 1.98 miles**
- **Area of Pool - 89 acres**

Geneva Dam Problems

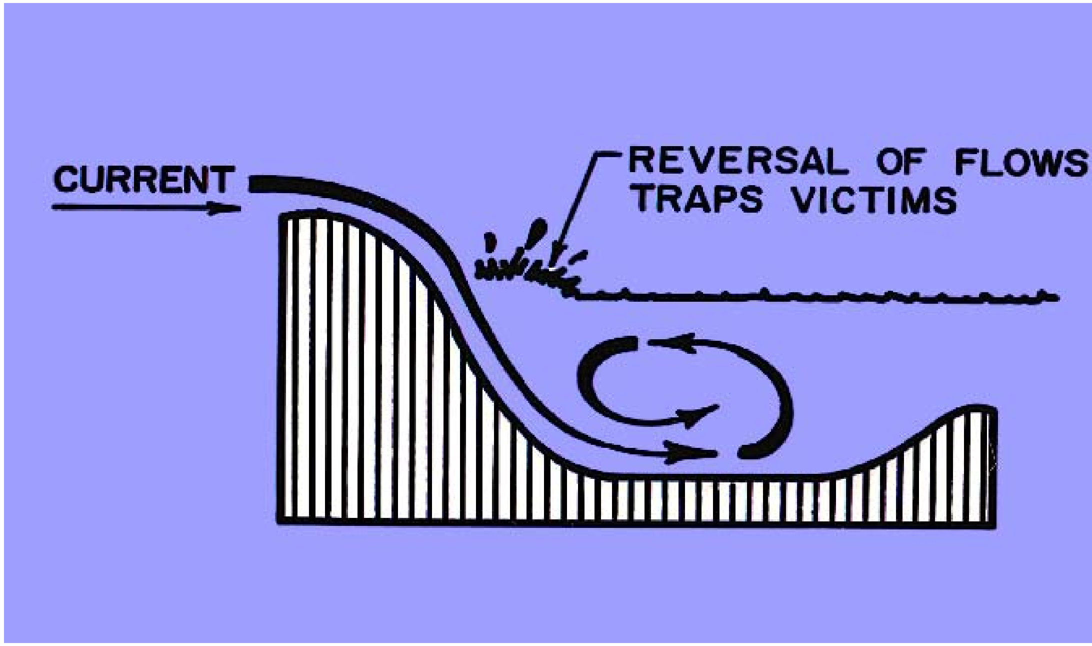
Public Safety

Fish Passage

Boat Passage

Public Safety

- Hydraulic Roller causes safety concerns

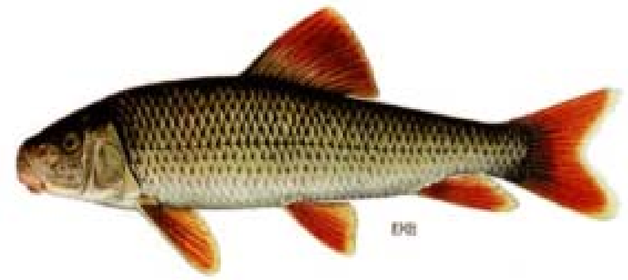


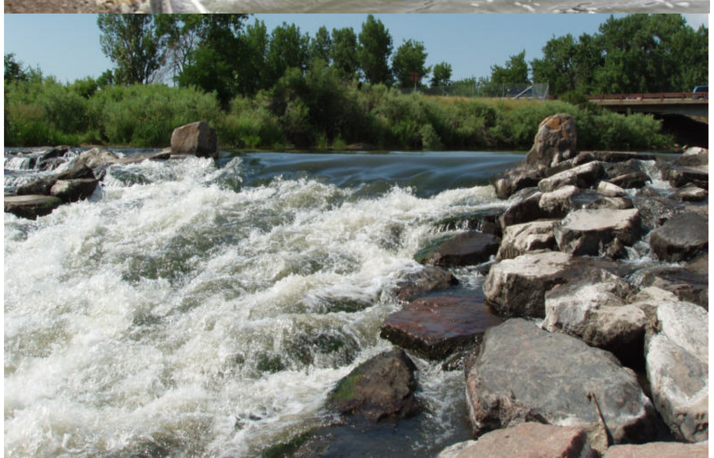
- Several dams on the Fox River have had recorded deaths

IDNR Requirements for Dams

Which we own or are likely to own and
For which State funds are to be expended

- Public Safety
- Ecological improvements to the river
- Development of recreational opportunities





Potential Dam Alternatives

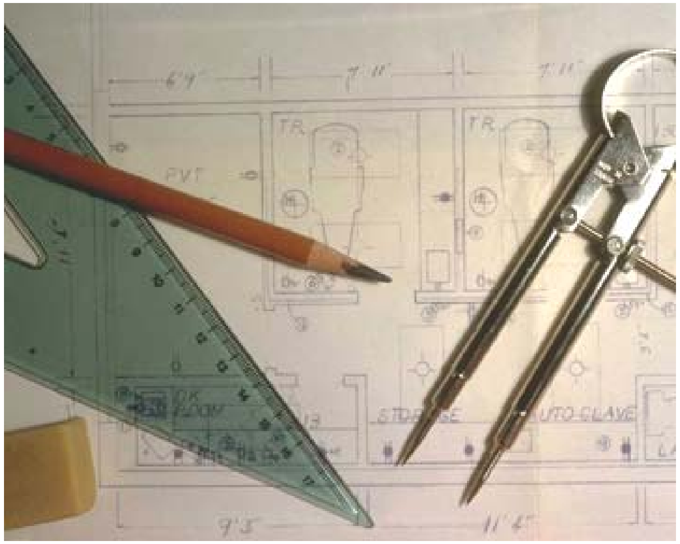
* Dam Removal

* Dam Modification
(Spillway Steps & Fish Ladder)

* Rock Ramp
(Temporary or permanent)

Criteria for Design of Replacement Structure

- Fish Passage
- Flood Conveyance
- Long Term City Planning
- Cost Effectiveness
- River Trails



- Boat Passage
- Safety
- Healthy Ecosystem
- Sediment Transport
- Predictable Results

Objectives of Geneva Dam Study

- **Identify suitable methodologies to define hydraulic characteristics and alternatives to minimize roller problem**

- **Development of methodologies to support the sizing of a temporary rock ramp downstream of Geneva Dam:**
  - **To minimize existing “roller“ for up to or over a 5-year frequency flow event**
  - **Rock ramp stable up to 100-year frequency flow**
  - **20-year expected project life**

MISSION:

Find a computer model that:

IMPOSSIBLE

1. Will simulate the hydraulics of

2. Wi... desk top computers;

3. Wi... mal training to use; and

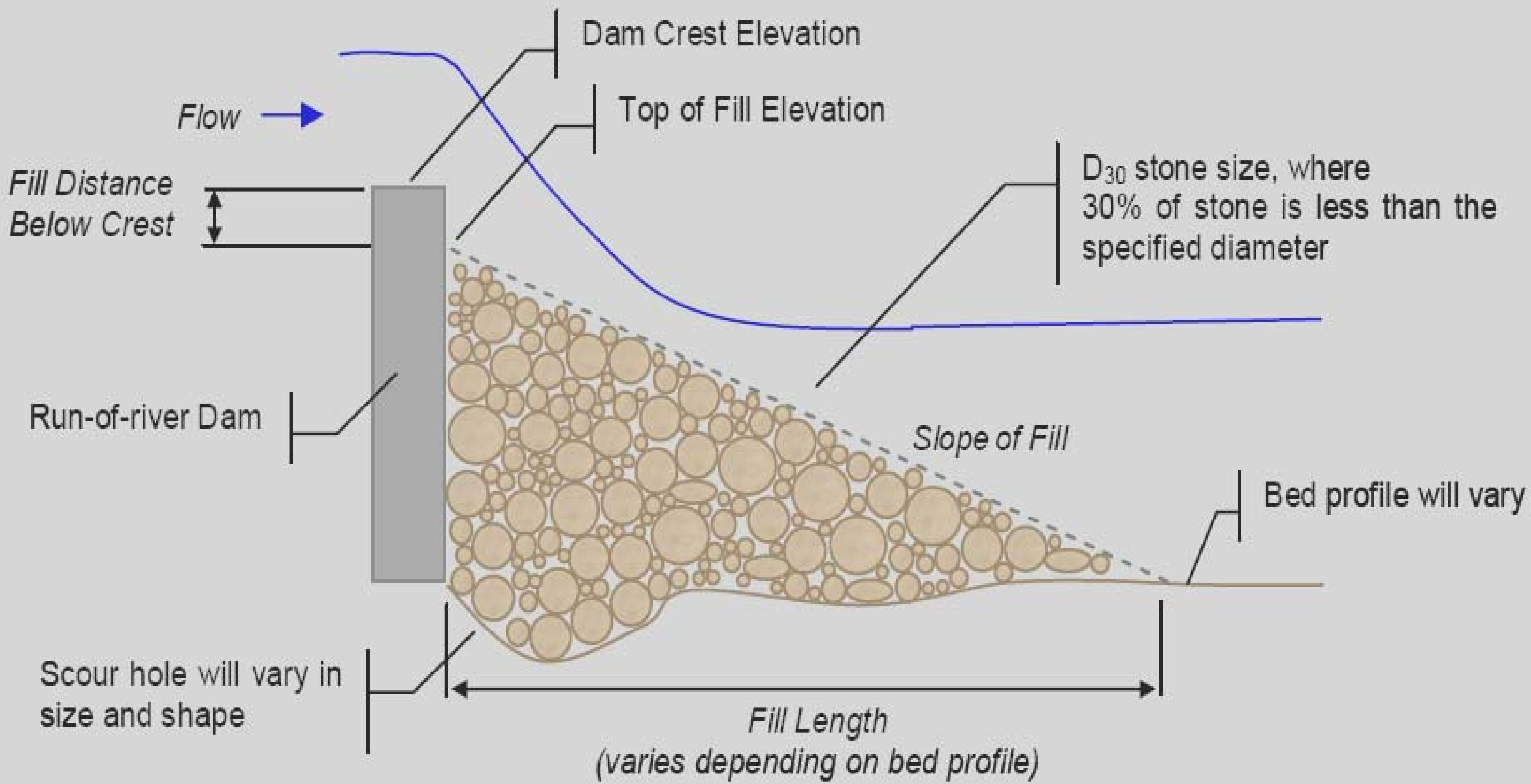
4. Is inexpensive.

Use of 1-D (HEC-RAS) Model

- **Conditions suitable for 1-D (HEC-RAS) modeling:**
  - **A design unit discharge along dam crest can be assumed.**
  - **Approaching flows are generally perpendicular to the weir.**
  - **Design water velocities have insignificant lateral component along riprap slope.**

- **Conditions requiring 2D/3D modeling:**
  - **Alternatives involving significant lateral or vertical variations in flow field, such as notches or unusual upstream flow alignment.**
  - **Physical conditions (bathymetry/geometry) resulting in 2D/3D flow field.**

Rock Ramp Sizing Evaluation


Dam Crest Elevation
Top of Fill Elevation
Flow
Fill Distance Below Crest
D30 stone size, where 30% of stone is less than the specified diameter
Run-of-river Dam
Slope of Fill
Bed profile will vary
Scour hole will vary in size and shape
Fill Length
(varies depending on bed profile)

Geneva Dam Rock Ramp Sizing Approach

- **Select design flow:**
  - **Minimize roller at 5-year frequency**
  - **Stable ramp at 10-, 25-, and 100-year frequencies**

- **Obtain design velocities and water depth:**
  - **HEC-RAS modeling.**
  - **Using 5% and 10% rock ramp slopes.**
  - **Using two Manning's n: 0.035 and 0.07.**
  - **Mixed flow turned on.**

- **Compare riprap sizes via four methodologies:**
  - **Rock ramp sizing spreadsheets.**

- **Recommend final sizes and gradation.**

Riprap Sizing Methods Examined

- **Four Methods Evaluated:**
  - **U.S. Army Corps of Engineers' (COE) method for steep slopes (from EM 1110-2-1601).**
  - **Isbash Method, high turbulence (from EM 1110-2-1601).**
  - **Frizell, Ruff and Mishra method for overtopping flows.**
  - **Hydraulic Engineering Circular 15, Design of Roadside, Channels with Flexible Linings (HEC-15, FHWA).**

U.S Army Corps of Engineers Method for Steep Slopes (EM 111-2-1601)

$$D_{30} = \frac{1.95\ S^{0.555}\ q^{2/3}}{g^{1/3}}$$

Where: S = Slope of bed , q = unit discharge

- **Thickness = 1.5 x D_{100}**
- **Slope can range from 2 to 20%**
- **Assumes no tailwater but horizontal extension of the ramp will minimize this limitation**

Isbash Method

$$\boxed{D_{50} = \frac{V_a^2}{2gC^2\left(G_s - 1\right)}}$$

D_{50} = stone size, ft

V_a = average Channel Velocity, ft/s

G_s = specific gravity of stone (γ_s / γ_w)

g = acceleration of gravity, ft/s^2

C = 0.86 for high turbulence zones

= 1.20 for low turbulence zones

Frizell, Ruff, and Mishra

$$\frac{V_i}{\sqrt{gD_{50}}} \cdot 2.48 S^{0.58} C_u^{\cdot\, 2.22}$$

V_i = interstitial velocity (m/s)

D_{50} = initially determined from design curves

g = gravitational constant (9.81 m/s2)

S = embankment slope

C_u = coefficient of uniformity = D_{60}/D_{10}

FHWA HEC-15 for Steep Slopes

$$n = \frac{\alpha\, d_a^{1/6}}{\sqrt{g}\; f(Fr)\; f(REG)\; f(CG)}$$

d_a = average flow depth in the channel

g = acceleration due to gravity

Fr = Froude number

REG = roughness element geometry

CG = channel geometry

α = unit conversion constant, 1.0 (SI) and 1.49 (CU)

FHWA HEC-15 for Steep Slopes

$$f(Fr) = \left(\frac{0.28Fr}{b}\right)^{\log(0.755/b)}$$

$$f(REG) = 13.434\left(\frac{T}{D_{50}}\right)^{0.492} b^{1.025(T/D_{50})^{0.118}}$$

$$f(CG) = \left(\frac{T}{d_a}\right)^{-b} \qquad b = 1.14\left(\frac{D_{50}}{T}\right)^{0.453}\left(\frac{d_a}{D_{50}}\right)^{0.814}$$

T = channel top width (ft)

Riprap Ramp Results

Return Period	Channel Slope	Manning's n	Methodology: COE-EM1601-1 D_{30} (ft)	Methodology: COE-EM1601-Isbach D_{50} (ft)	Methodology: FrizellRuffMishra D_{50} (ft)	Methodology: FHWA D_{50} (ft)	Average D_{50} (ft)
5-yr	5%	0.035	0.72	2.23	0.77	0.74	1.25
10-yr			0.77	2.38	0.84	0.76	1.33
50-yr			1.00	3.01	0.89	0.88	1.59
100-yr			1.06	3.15	1.10	0.91	1.72
5-yr		0.07	0.72	2.11	0.77	0.73	1.20
10-yr			0.77	2.16	0.83	0.77	1.25
50-yr			1.00	2.33	0.87	0.92	1.37
100-yr			1.06	2.37	1.08	0.96	1.47
5-yr	10%	0.035	1.05	3.09	0.89	1.25	1.75
10-yr			1.13	3.26	0.97	1.35	1.86
50-yr			1.47	3.91	1.11	1.80	2.27
100-yr			1.56	4.05	1.19	1.92	2.39
5-yr		0.07	1.05	2.11	0.87	1.42	1.47
10-yr			1.13	2.16	0.96	1.54	1.55
50-yr			1.47	2.33	1.07	2.17	1.86
100-yr			1.56	2.37	1.16	2.35	1.96

Gradation Determination Based Upon COE Gradations

Limits of Stone Weight, lb[1], for Percent Lighter by Weight

D_{100}(max) in.	100 Max	100 Min	50 Max[2]	50 Min	15 Max[2]	15 Min	D_{30}(min) ft	D_{90}(min) ft
Specific Weight = 165 pcf								
9	36	15	11	7	5	2	0.37	0.53
12	86	35	26	17	13	5	0.48	0.70
15	169	67	50	34	25	11	0.61	0.88
18	292	117	86	58	43	18	0.73	1.06
21	463	185	137	93	69	29	0.85	1.23
24	691	276	205	138	102	43	0.97	1.40
27	984	394	292	197	146	62	1.10	1.59
30	1,350	540	400	270	200	84	1.22	1.77
33	1,797	719	532	359	266	112	1.34	1.96
36	2,331	933	691	467	346	146	1.46	2.11
42	3,704	1,482	1,098	741	549	232	1.70	2.47
48	5,529	2,212	1,638	1,106	819	346	1.95	2.82
54	7,873	3,149	2,335	1,575	1,168	492	2.19	3.17

General Comments on Riprap Methods

- All these methods assume that the riprap is at least moderately angular and for temporary conditions only.
- The riprap methods and the ramp do not take into consideration ice or debris impacts.
- Because of the high turbulence, vibration of the riprap would tear filter fabric – recommend granular filter.
- Note that the COE method for steep slopes gives D_{30} for the representative riprap size whereas the others give D_{50}.
- To make the methods comparable, the D_{30} result was converted to an equivalent D50 using the formula $D_{30} = D_{50}\,(D_{15} / D_{85})^{0.33}$, which is related to the COE gradation method

Basis of Method Selection

- **Isbash method was developed for the construction of dams by depositing rock into running water. If the dumped rock did not slide or roll under those conditions, the rock size was considered stable - too conservative.**

- **HEC-15 method uses an arbitrary safety factor of 1.5 – overly conservative.**

- **For the Frizell et al. method, the unit discharge for the Geneva Dam exceeded those presented in the graph used in determining the D_{50} of the riprap and values had to be extrapolated.**

- **The COE method shows reasonable results for the full range of ramp slopes and discharges and was therefore recommended for design of the riprap for Geneva Dam.**

5% or 10% Slope?

- **5% or 10% slopes will minimize the formation of the dangerous hydraulic rollers for the 5-year flow events and will function properly per design requirements.**
- **Therefore, recommendations for either a slope of 5% or 10% depend on the costs.**
- **The 10% ramp slope has a larger gradation (D_{30} of 1.70 feet) than the 5% ramp slope (D_{30} of 1.10 feet) but would have a smaller overall riprap volume.**
- **Since the costs for riprap is a combination of availability of large sized rock as the volume of riprap, the recommended ramp slope should be based upon local rock supply conditions.**

COSTS

<u>CORPS METHOD 10% SLOPE</u>

Less rock but bigger rock

19,800 TONS

$89/TON

$2,485,000

<u>CORPS METHOD 5% SLOPE</u>

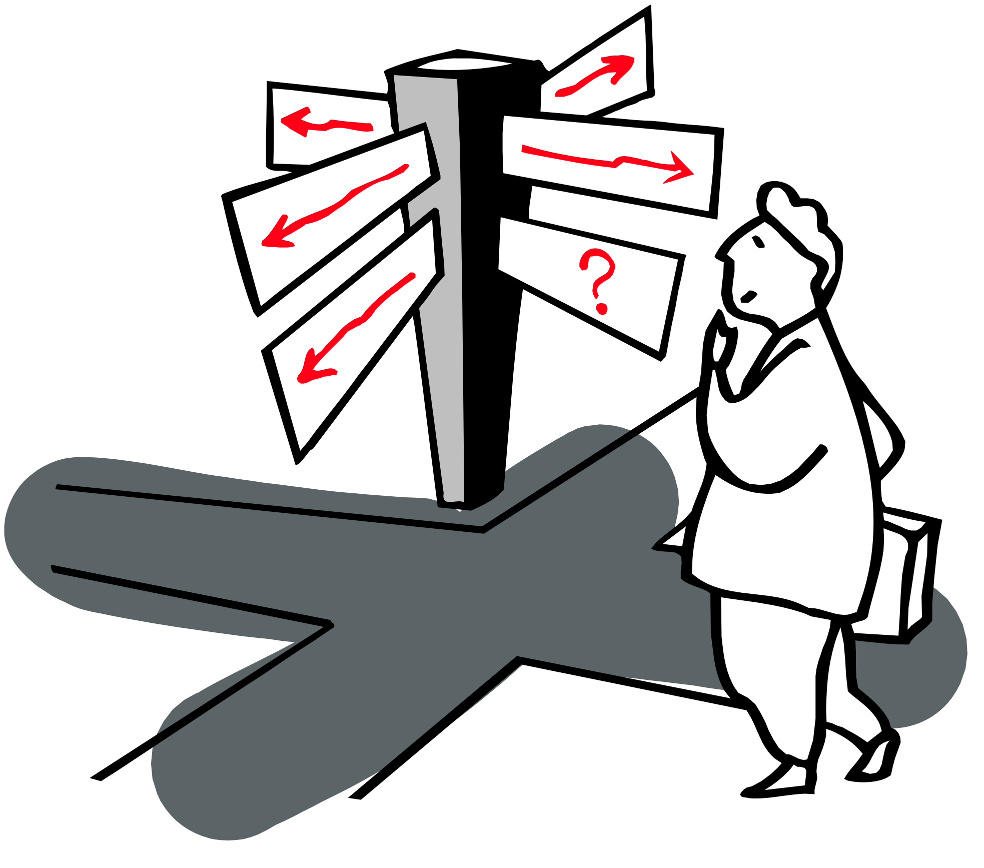
More rock but smaller rock

35,700 TONS

$85/TON

$3,800,000

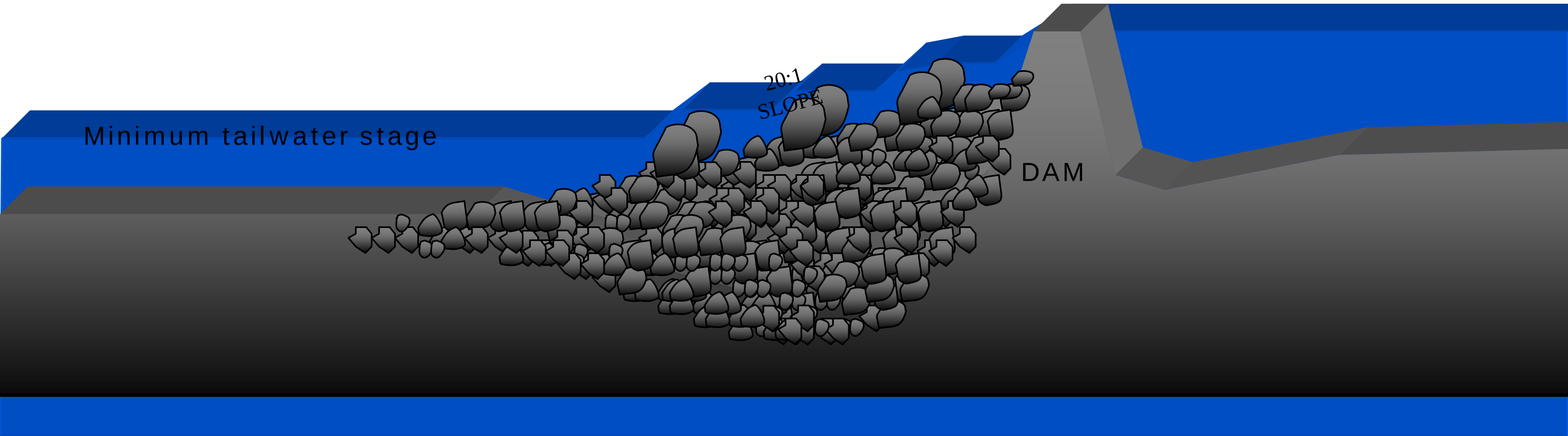
Where are we headed now?



Investigate Temporary Rock Ramp Placement

INVESTIGATE PERMANENT ROCK RAMP DESIGN ARCH RAPIDS LONGITUDINAL PROFILE (consider Luther Aadland Design)

Public Safety
Fish Passage
Recreational Boat Passage



Investigate Dam Removal

Compare to Stair Step Dam Modification at Yorkville

$2,900,000

Thank you!

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Frizell, Ruff, and Mishra

$V_{ave} = V_i \times n_p$ **n_p = porosity of the riprap**