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Alluvial Fan Flood Hazard Mapping and Dam Failure Analysis using USGS Diffusion Hydrodynamic Model

by Neil M. Jordan, P.E.

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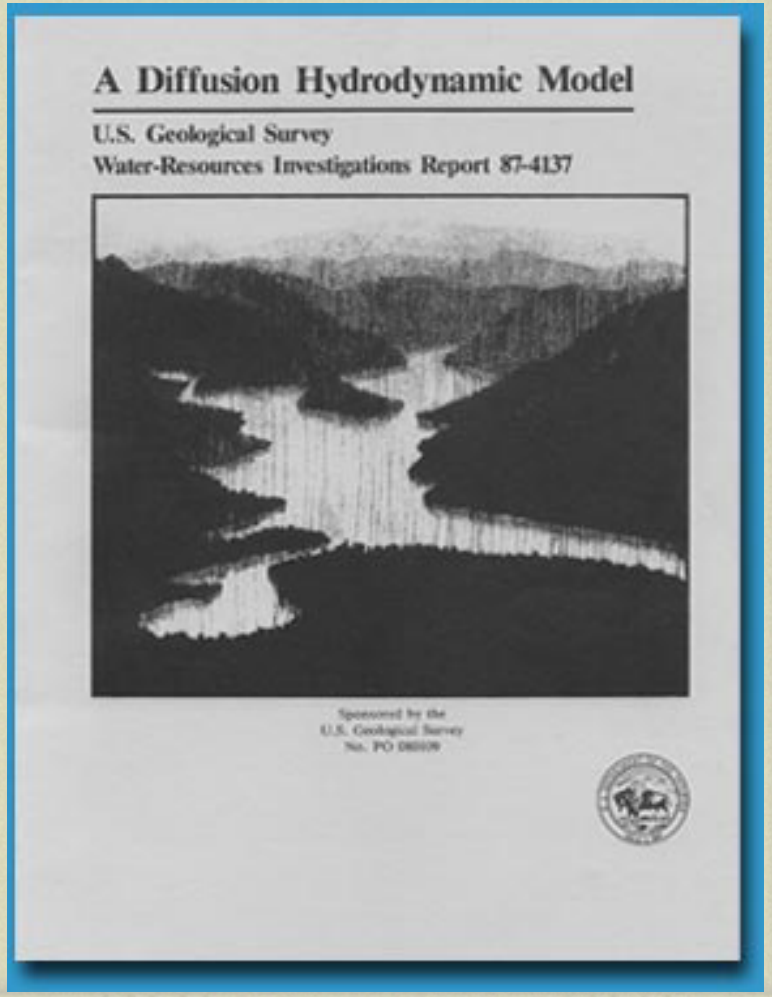
USGS DIFFUSION HYDRODYNAMIC MODEL

USGS DHM 21

Developed by Drs. T.V. Hromadka and C.C. Yen for dam break analysis of Long Valley Dam (Crowley Lake) above Bishop, CA.



Diffusion Hydrodynamic Model

- Dam break flow passing over alluvial fan involves two-dimensional unsteady nonuniform unconfined overland flow, cross-boundary flow, backwater effects, and floodplain-channel interaction.
- DHM provides all the tools for analysis.

Unconfined

- Flow bounded by topography or intentional critical depth, or intentional rating curve.
- Flow not bounded by prescriptive limits of cross sections or arbitrary boundaries.
- No unintentional Moses Effects.

The Moses Effect

Boundary elements should be dry.

If not, extend model to topographic boundary.

DHM Governing Equations

- Saint-Venant equations:
- Continuity – conservation of mass.
- Conservation of momentum, with friction slope approximated from Manning's equation.
- Two sets of equations, one for the x-direction, one for the y-direction.

S-V Momentum Terms

Local + Convective + Pressure + Gravity + Friction = 0

- **Gravity + Friction terms = Kinematic Wave**
- **Pressure + Gravity + Friction terms = Diffusion Wave (DHM)**
- **All terms = Dynamic Wave**

….but acceleration (inertia) terms sum to nearly zero for Froude numbers less than ~ 4.

USGS DHM Testing

- Courant condition – time step variables.
- Supercritical flow.
- Grid element orientation.

Courant Condition

"$\Delta t \leq \Delta x/(V \pm c)$:

It's not just a good idea.

It's the law."

Courant, after Einstein, after USGS FEQ

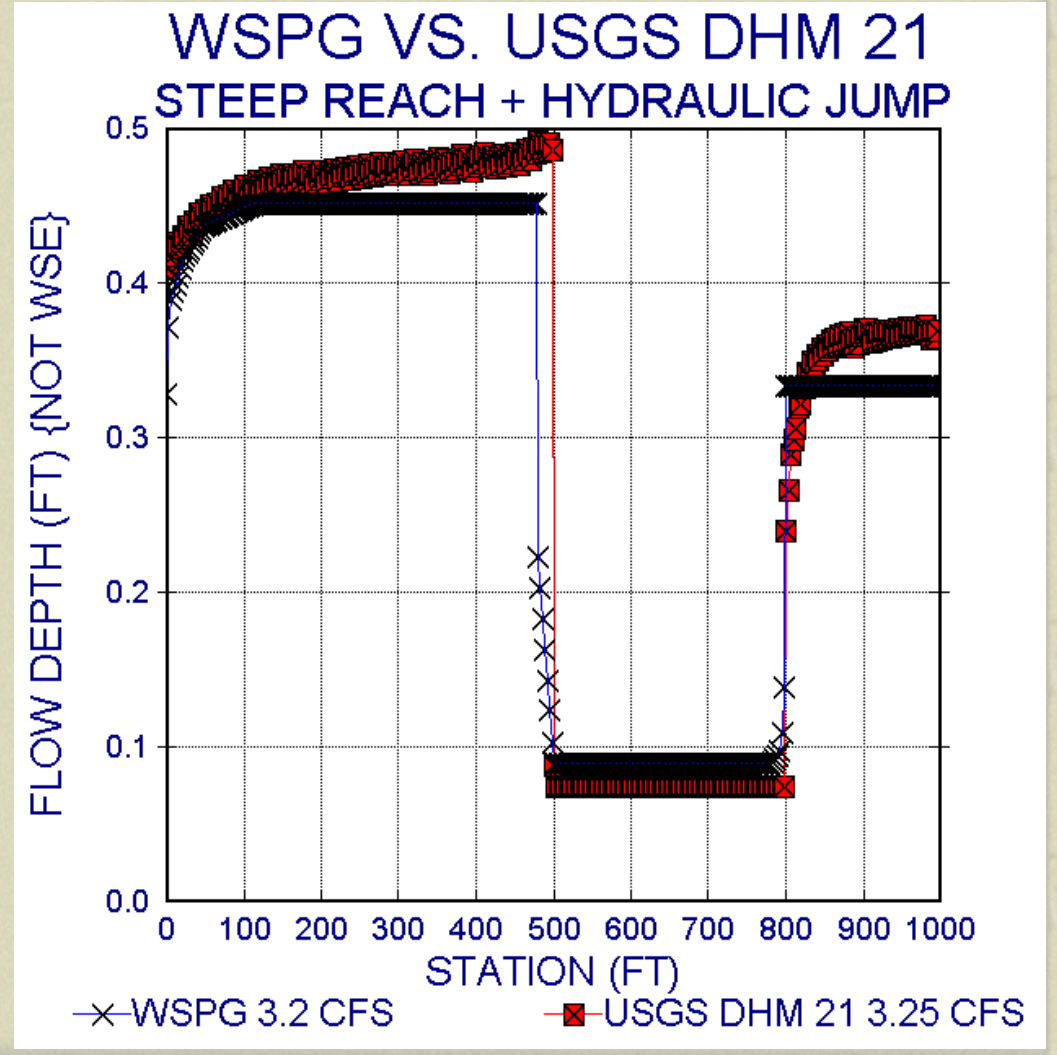
DHM Time Step Sensitivity

		Initial Estimate	Final Model
DTMIN	=	3 sec	2 sec
DTMAX	=	72 sec	20 sec
DTOL	=	0.4 ft	2 ft
DTOLP	=	16 %	25 %
Dp*	=	7.420 ft	7.903 ft

* Maximum depth for grid element #2058

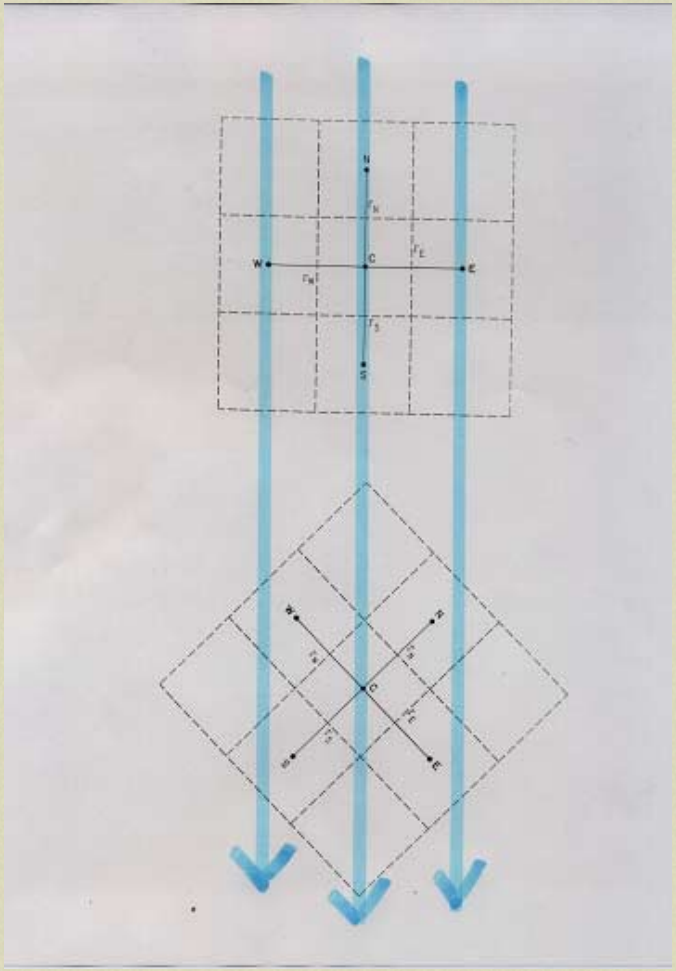
Supercritical Flow Test

- Critical depth control @ 0 ft
- Mild slope 0 ft – 500 ft
- Hydraulic jump @ ~470-500 ft
- Grade break @ 500 ft
- Steep slope 500 ft – 800 ft
- Grade break@ 800 ft
- Mild slope 800+ ft

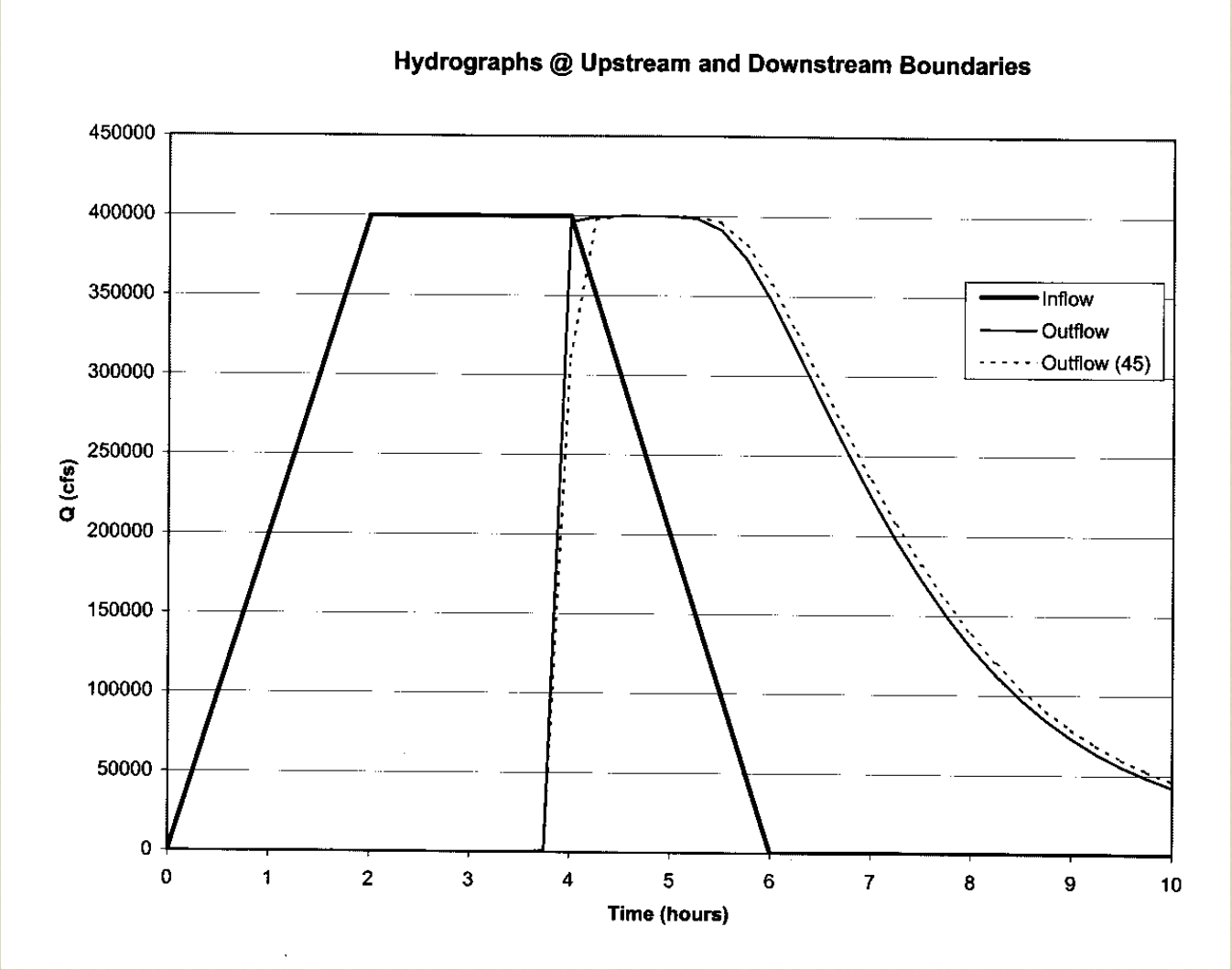


Grid Element Orientation Test

- Exact solution to flow equations if grid elements aligned with flow direction.
- Maximum error if grid elements aligned 45 degrees to flow direction.



Grid Element Orientation Test



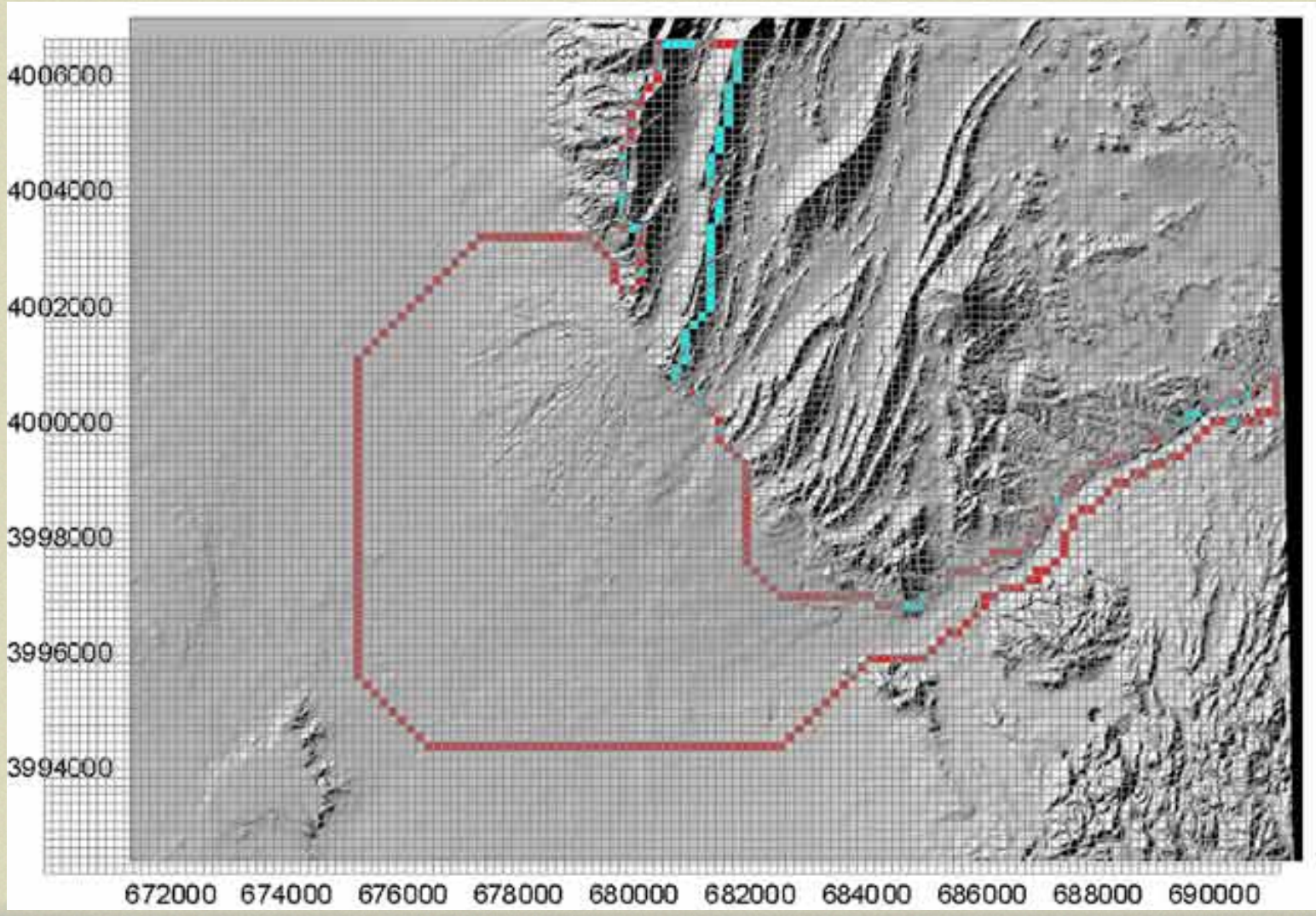
USGS DHM Model Development

- Digital terrain data – USGS Digital Elevation Models.
- Import and join DEMs with surface modeling program.
- Apply DHM grid to surface model.
- Extract DHM grid center coordinates – use surface modeling program to calculate elevations and write geometry output file.
- Import geometry into DHM data file.

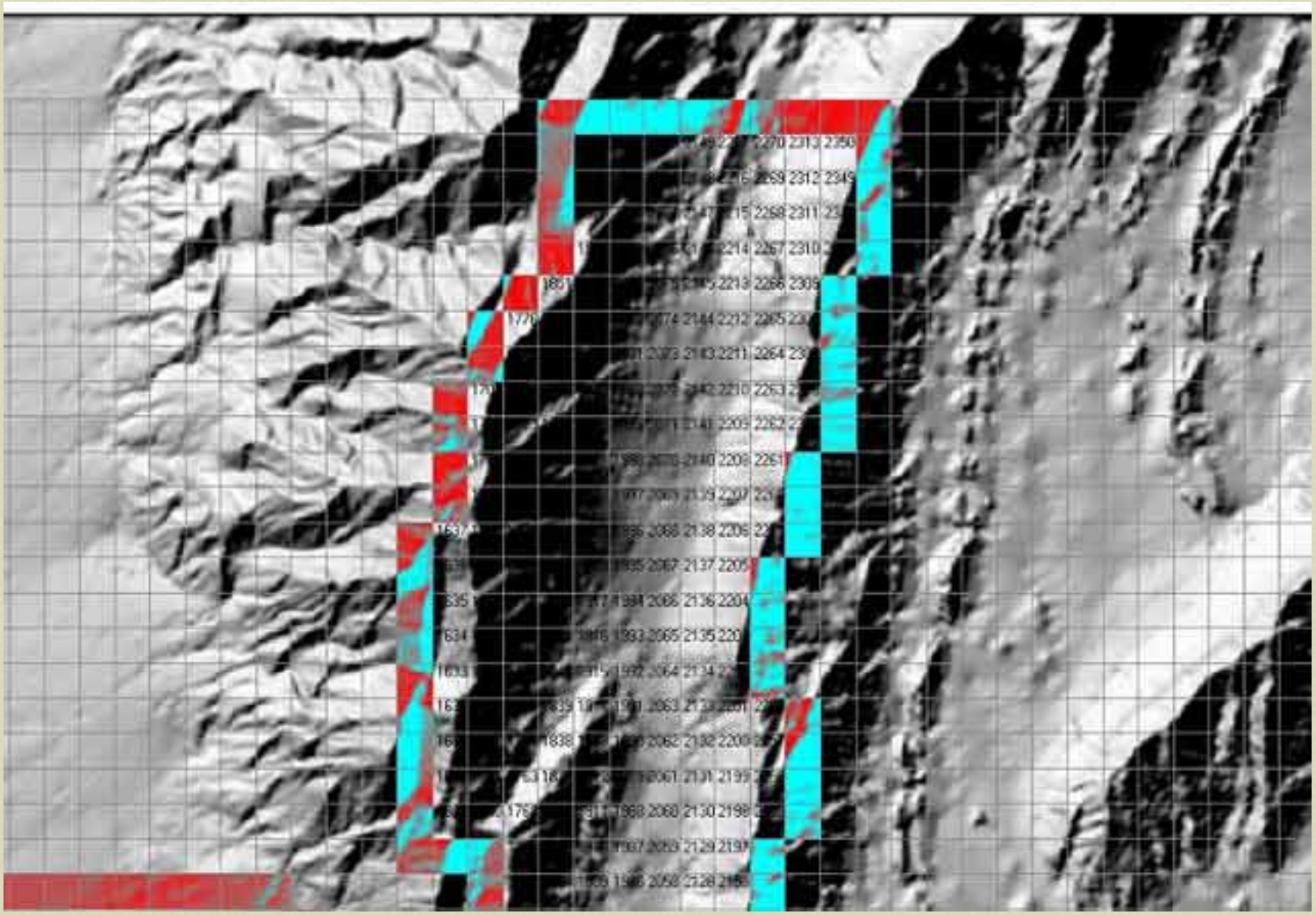
Develop & Apply DHM Grid

- "Grid Development System" (GDS) developed by Venezuelan Central University for FLO-2D.
- Use GDS only to calculate grid element center coordinates and boundary elements, but not elevations.
- GDS output file is identical to DHM input file, but with elevations calculated by surface modeling program.

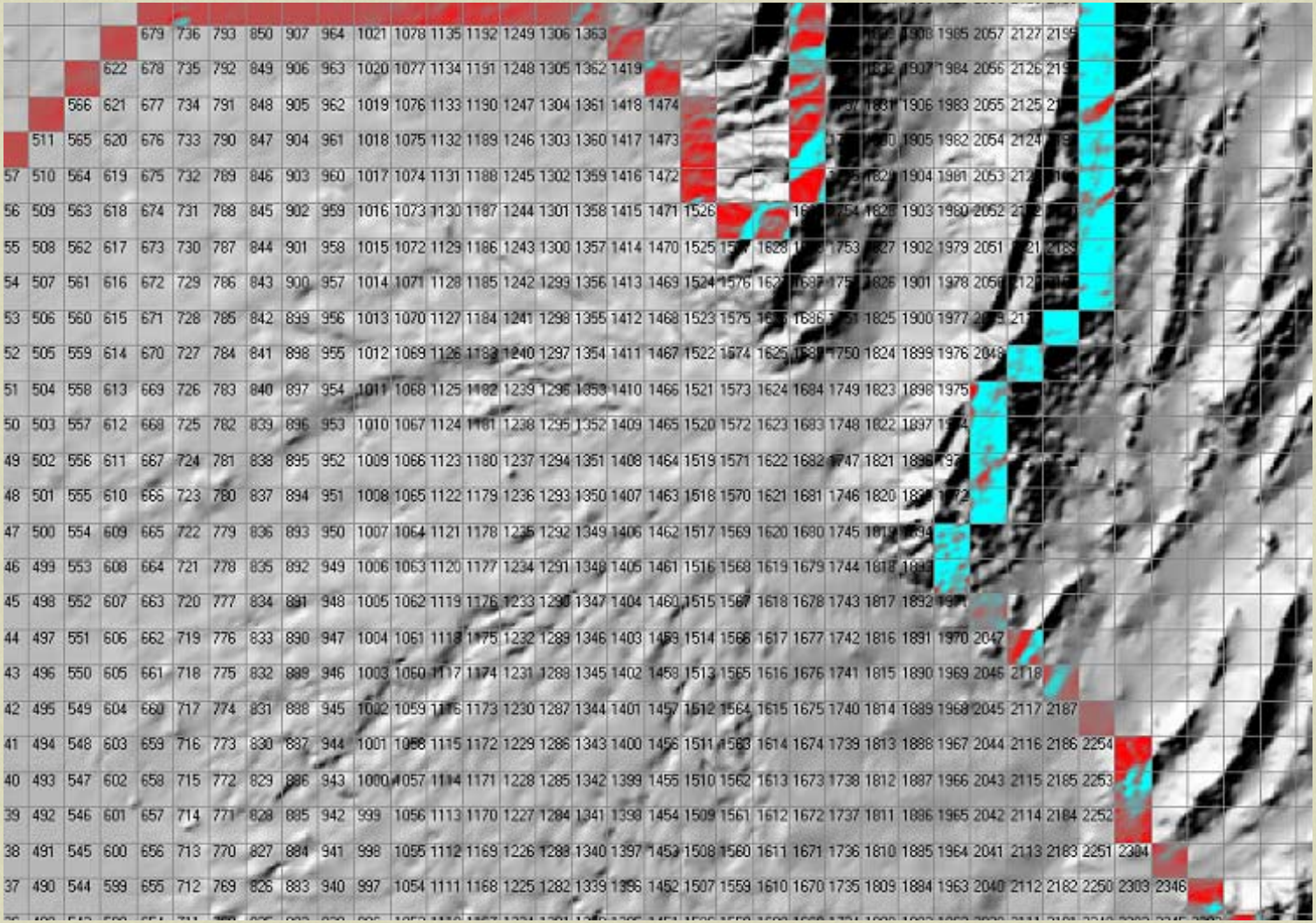
DHM Grid – 2723 Grid Elements



DHM Grid – Dam Area



DHM Grid – Alluvial Fan



USGS DHM Model Refinement

- Inspect model for unintended "dams" on flat surfaces or thalwegs caused by diagonal pairs of grid elements being higher than opposing diagonals.
- Add open channel elements.
- Check for The Moses Effect.

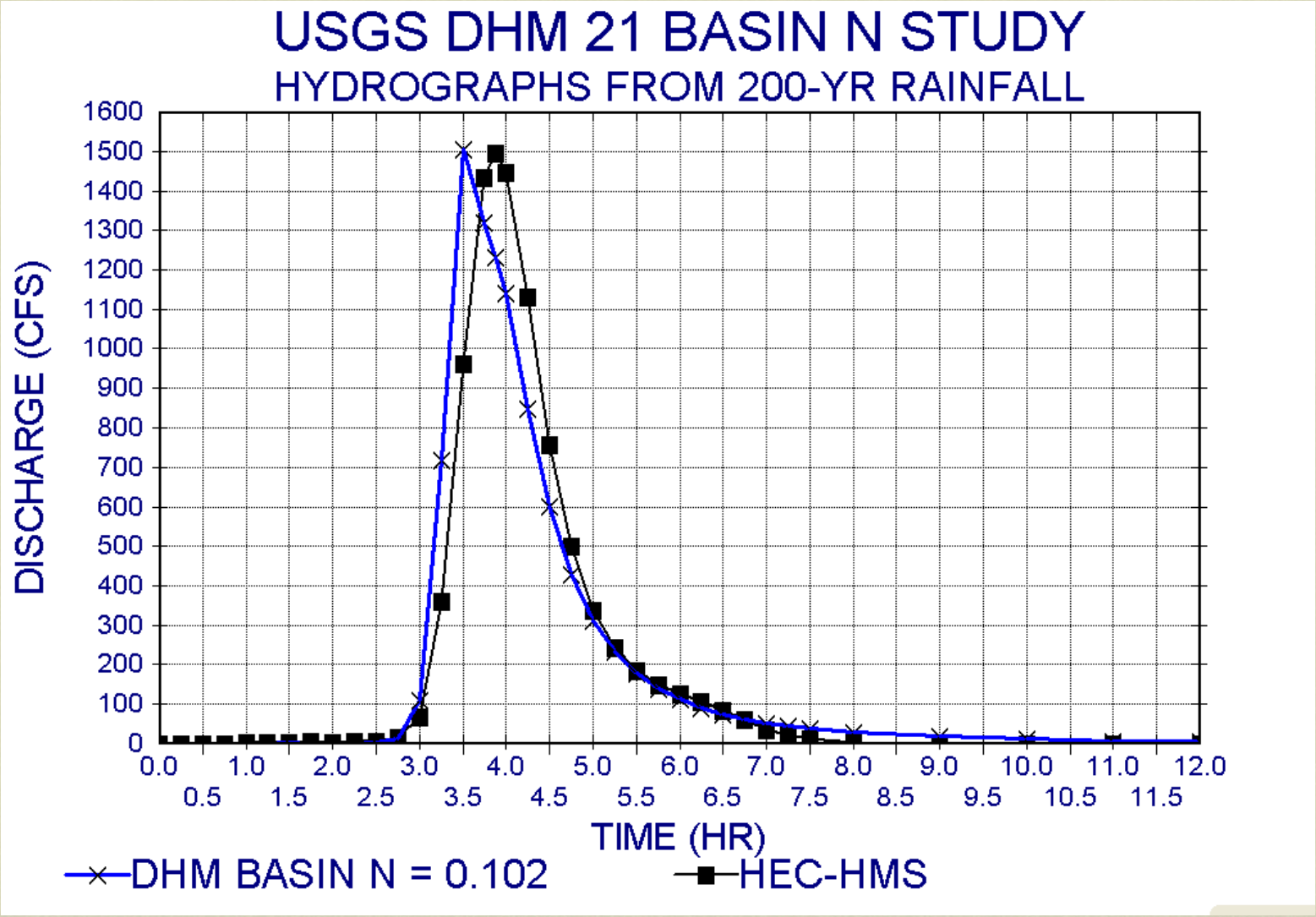
DHM Model Characteristics

	Area (sq mi)	Area (ac)	~Length (mi)
Upper (dam) basin:	1.24	794	1.7
Total area:	24	15,500	14

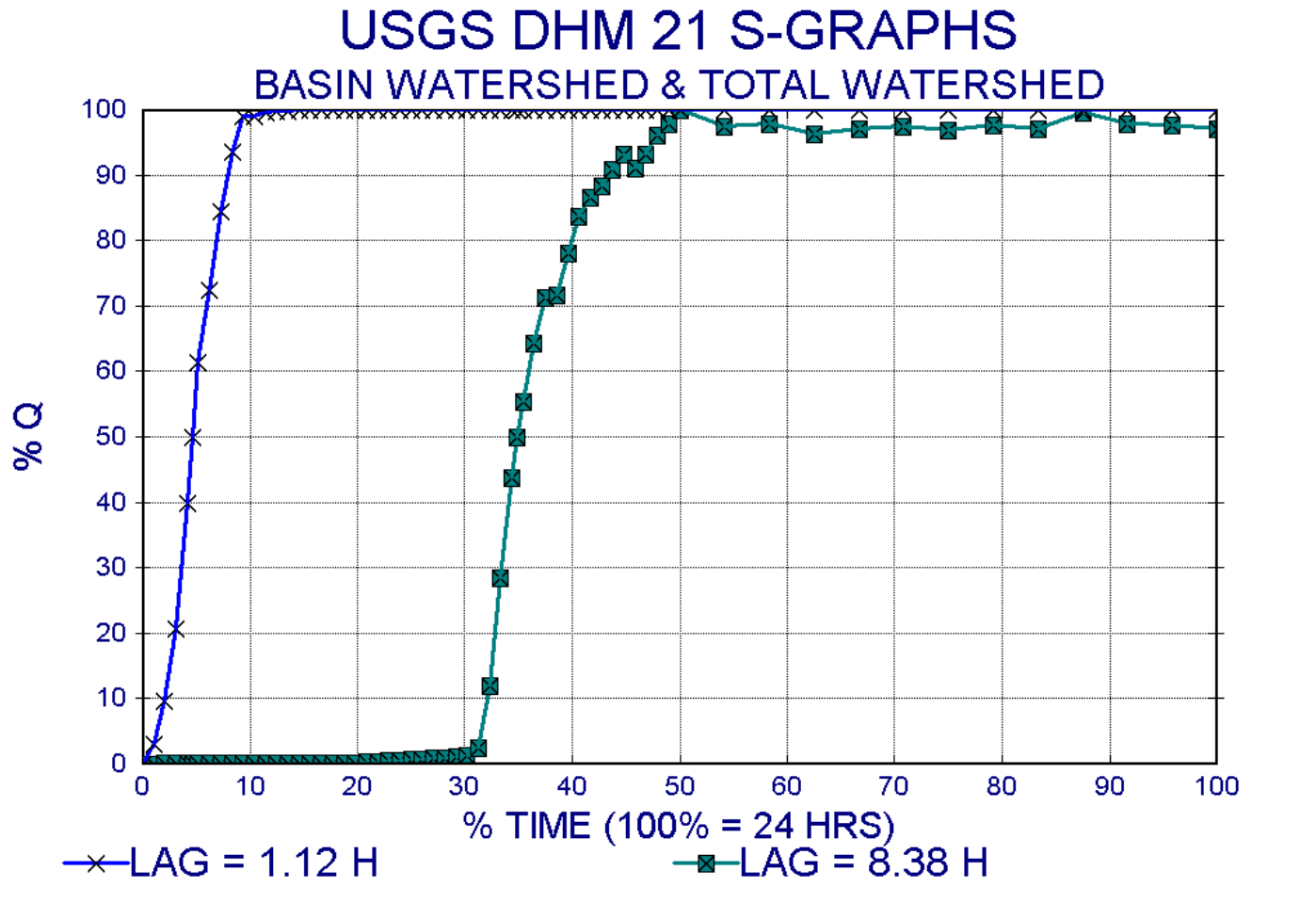
USGS DHM Model Calibration

- Calculate dam tributary area rainfall-runoff using HEC-HMS and DHM.
- Adjust DHM global roughness (basin N) to match DHM to HEC-HMS peak discharge.
- Calculate summation hydrographs (s-graphs).

Rainfall-Runoff Hydrographs



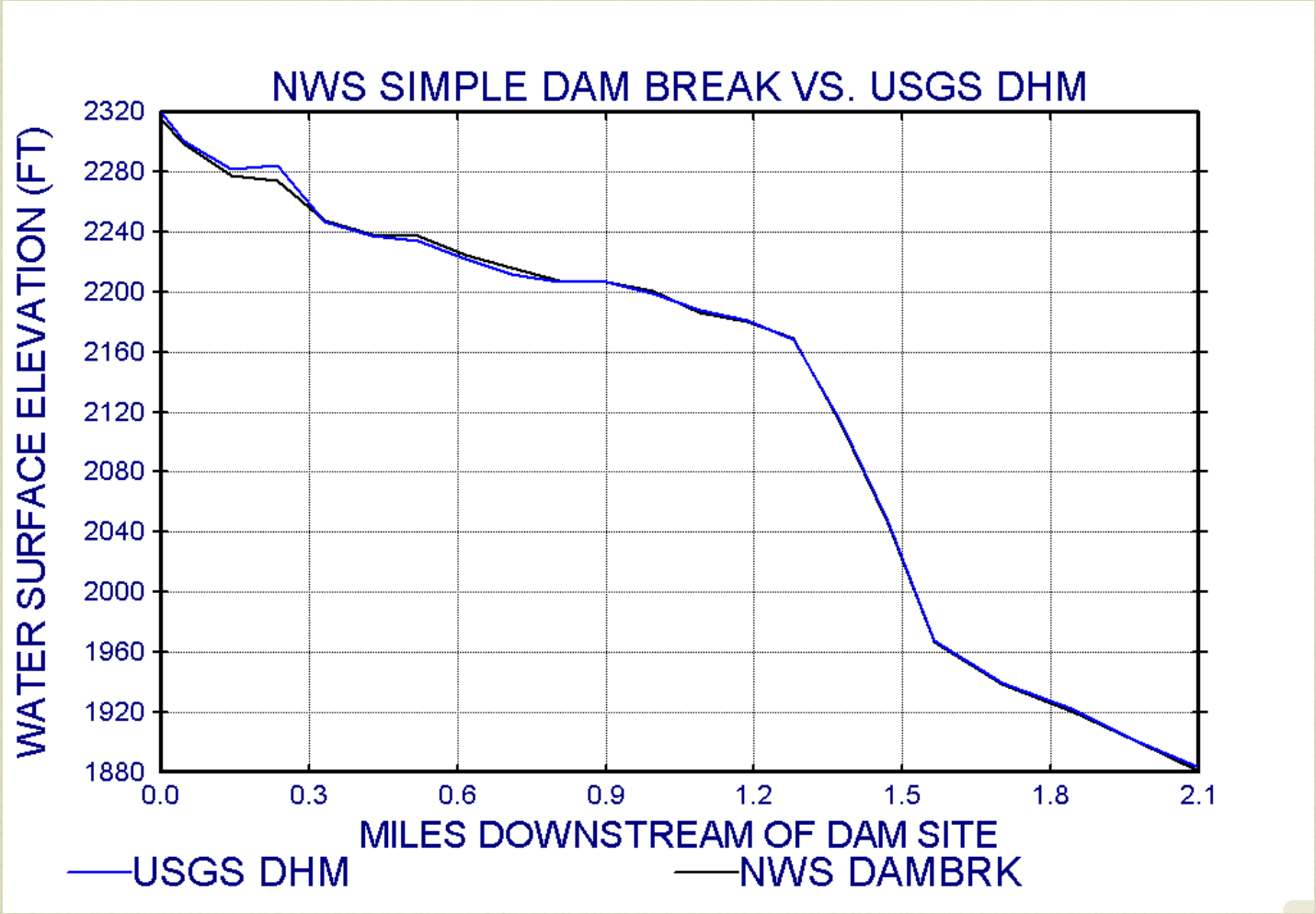
Unit Rain Summation Hydrographs (S-Graphs)



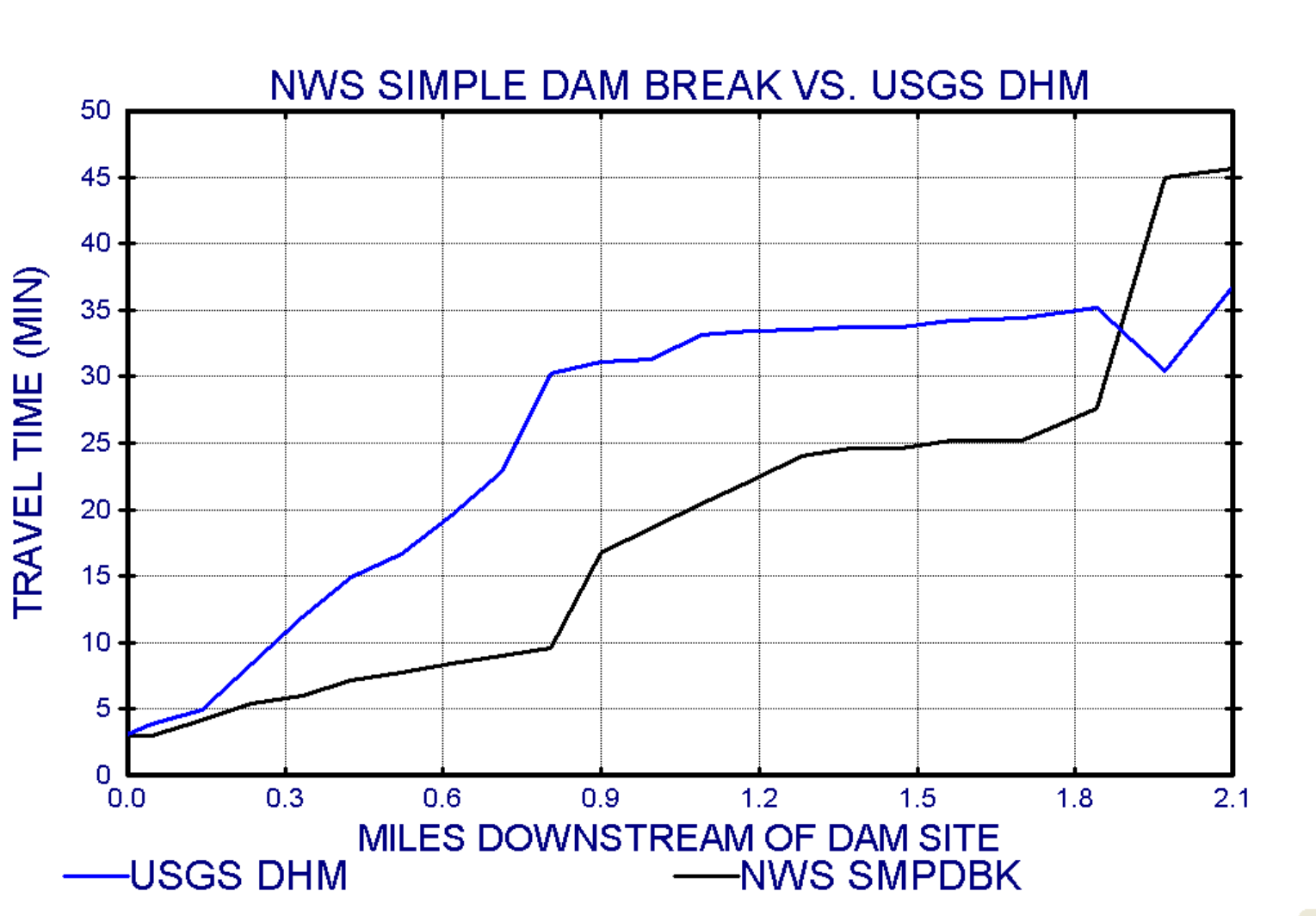
Dam Failure Analysis

- Define dam breach hydrograph for ~40 ft high, ~150 ac-ft earth dam.
- Compare DHM performance with NWS Simplified Dam Break model for 1-D part (Qp = 32,695 cfs).
- Calculate dam breach hydrograph with NWS BREACH model (Qp = 34,826 cfs).
- Add 10-year, 6-hour rainfall hydrograph.
- Calculate flood, peak, and deflood times.

DHM vs. SMPDBK – WATER SURFACE ELEVATIONS



DHM vs. SMPDBK – TIME



DHM Output File

```
MODEL TIME(HOURS) =       3.70 (SECONDS) = 0.133E+05 (TOTAL TIMESTEP NUMBER) =   1.3E+03
        EFFECTIVE RAINFALL(IN/HR) =   0.13

    ***FLOOD PLAIN RESULTS***
       INFLOW  RATE AT NODE 2058 IS EQUAL TO       0.00
```

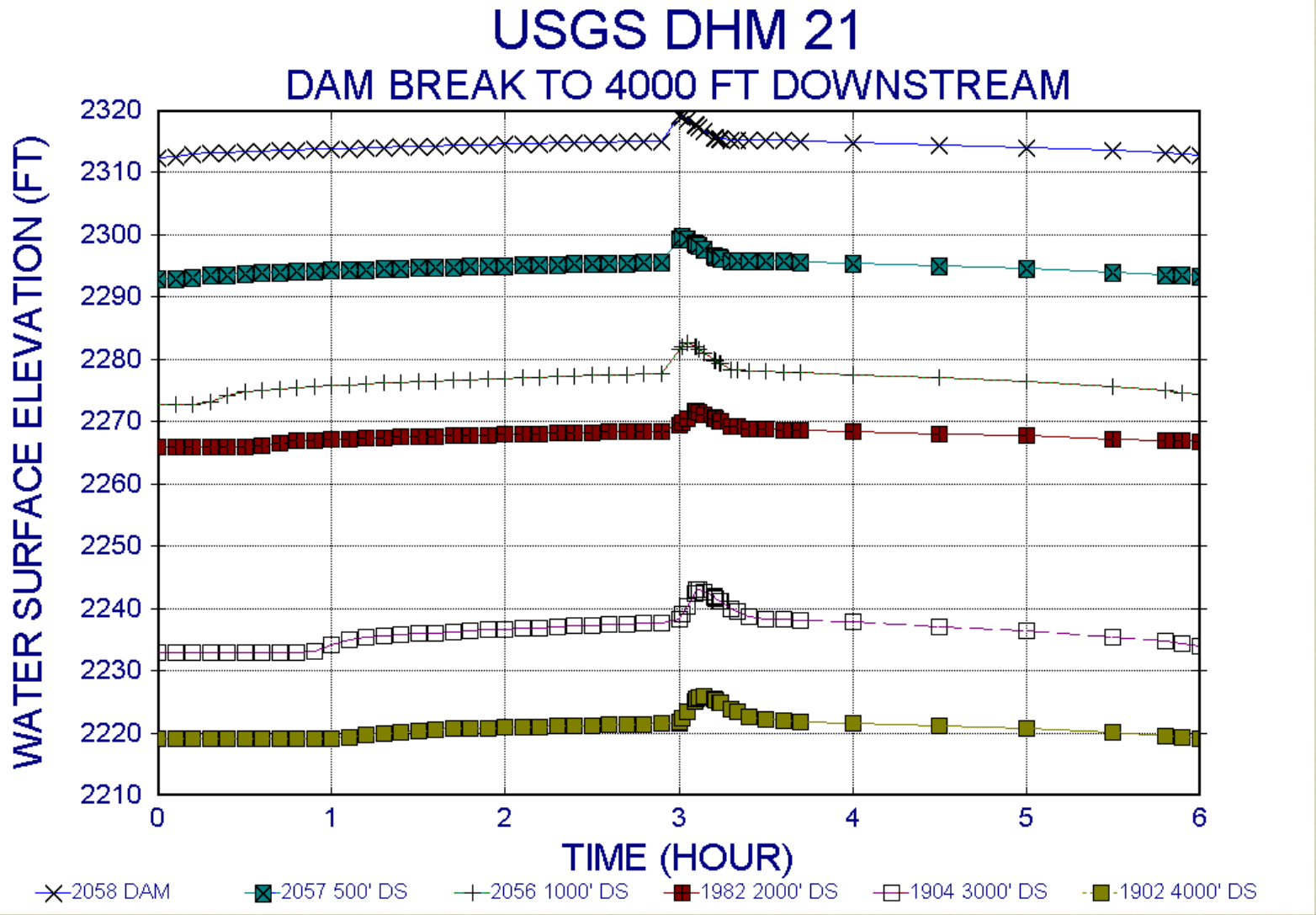
NODE	1	2	3	4	5	6	7	8	9	10
DEPTH	0.028	0.053	0.031	0.123	0.019	0.054	0.028	0.060	0.025	0.085
ELEVATION	1679.718	1679.163	1678.961	1678.423	1680.199	1676.674	1680.018	1680.520	1681.185	1678.495

NODE	11	12	13	14	15	16	17	18	19	20
DEPTH	0.057	0.021	0.050	0.027	0.041	0.105	0.069	0.031	0.076	0.051
ELEVATION	1677.607	1679.511	1678.760	1684.536	1684.911	1680.305	1680.269	1681.691	1681.586	1683.481

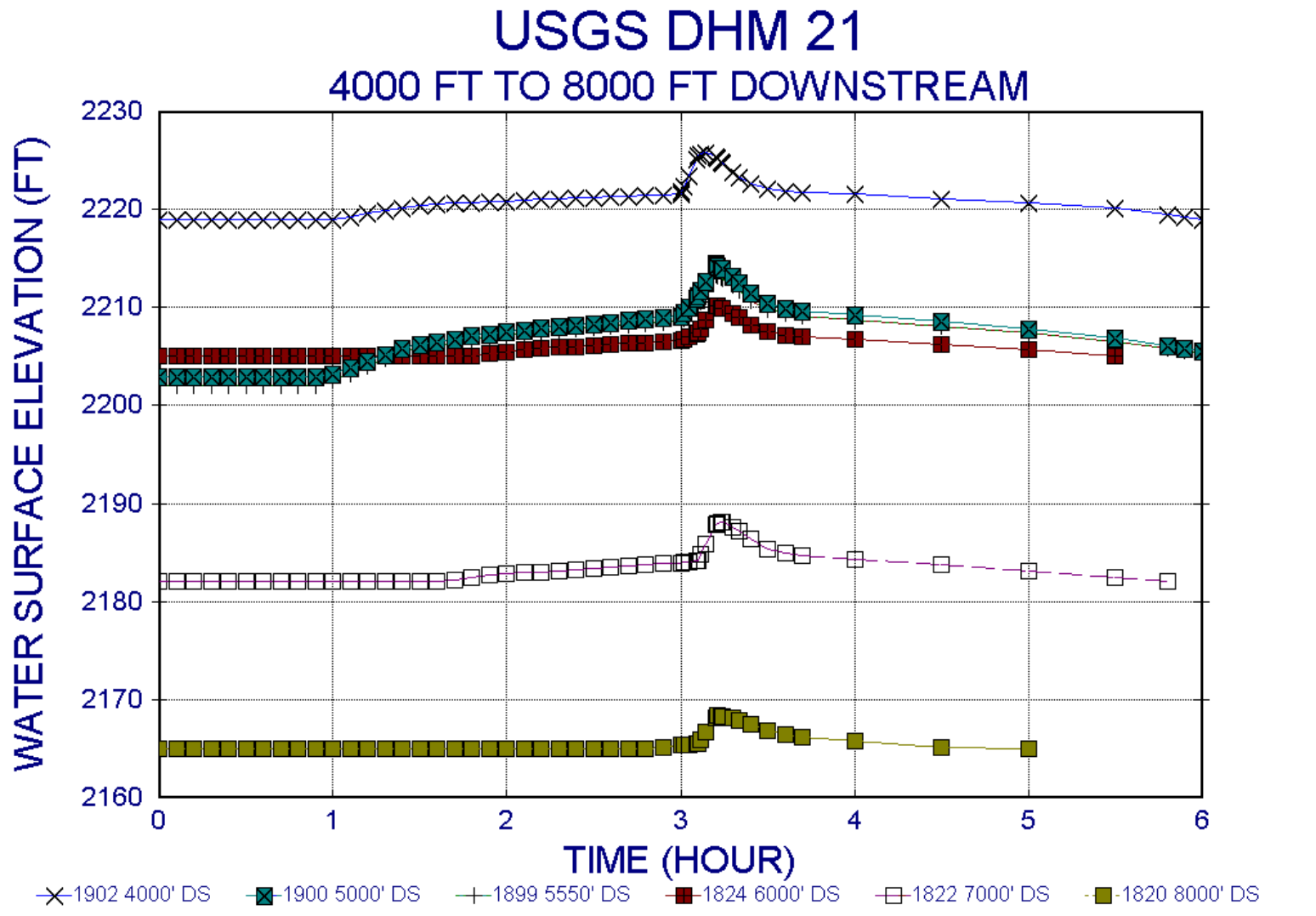
NODE	21	22	23	24	25	26	27	28	29	30
DEPTH	0.050	0.048	0.038	0.056	0.048	0.051	0.046	0.075	0.038	0.102
ELEVATION	1685.640	1687.828	1690.628	1691.236	1693.028	1694.701	1696.126	1696.675	1700.068	1700.142

NODE	31	32	33	34	35	36	37	38	39	40
DEPTH	0.050	0.053	0.048	0.038	0.027	0.047	0.083	0.020	0.122	0.026
ELEVATION	1702.110	1703.553	1705.478	1709.108	1711.397	1710.907	1709.673	1681.370	1671.202	1676.176

DHM Flood Hydrographs



DHM Flood Hydrographs



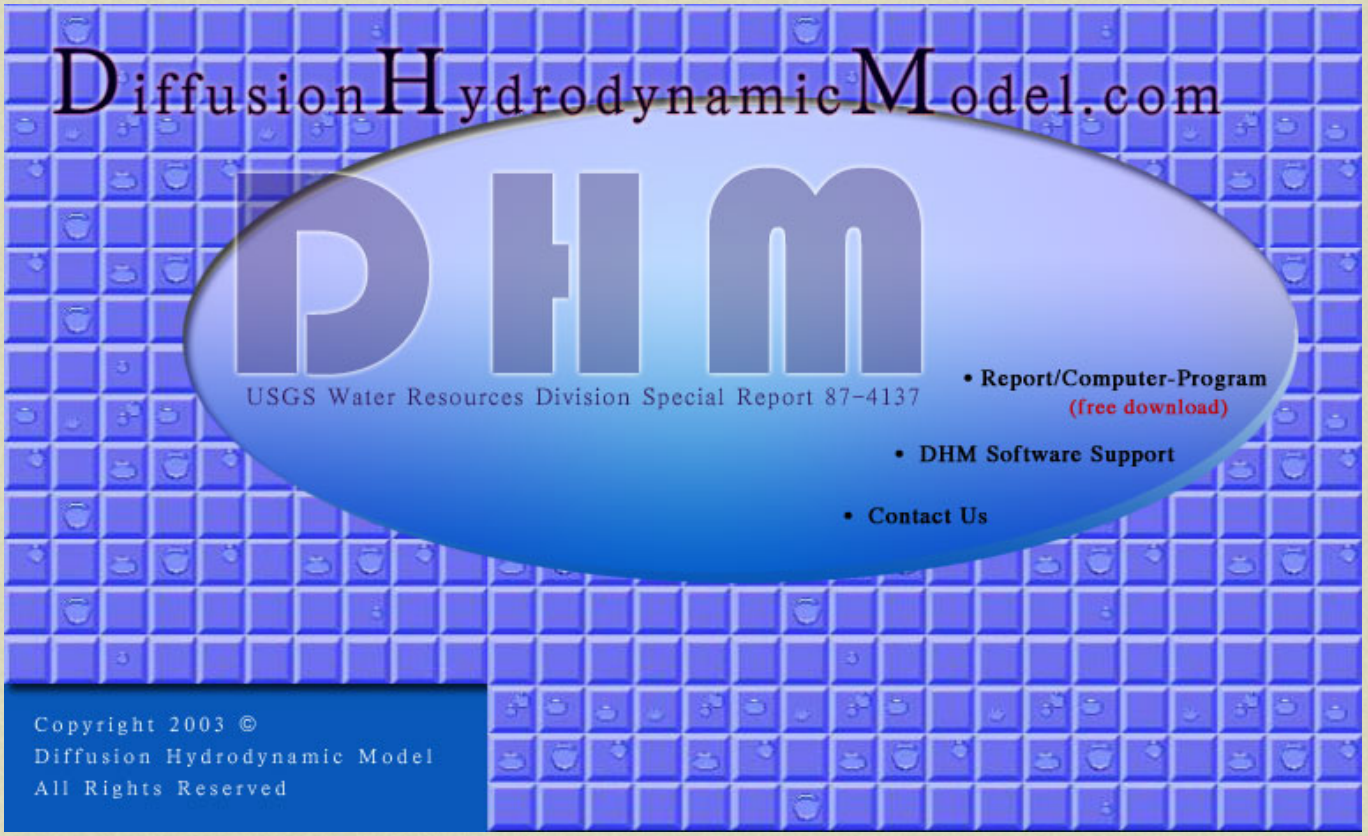
DHM Output Summary

NODE	DIST FROM DAM (FT)	PEAK FLOOD DEPTH (FT)	FLOOD TIME (HR)	PEAK TIME (HR)	DEFLOOD TIME (HR)	AVG WAVE VELOCITY (FT/SEC)
2056	1000	9.8	0.4	3.0	6.2	6.6
1982	2000	5.6	0.9	3.1	5.8	6.5
1902	4000	6.8	1.4	3.1	5.6	7.8
1824	6000	5.2	2.4	3.2	4.8	8.4
1820	8000	3.4	3.1	3.2	3.8	10.6
1818	10000	2.6	3.2	3.2	3.5	11.7
2627	8 MI	2.2	5.3	16	64	0.8
2719	12 MI	2.1	20	25	57	0.8

There is Hope

Environmental Modeling Systems, Inc. is implementing USGS DHM in their Surface Modeling System.

There is Support



A new DHM web site – download the USGS report, DHM program, code, the data input program.