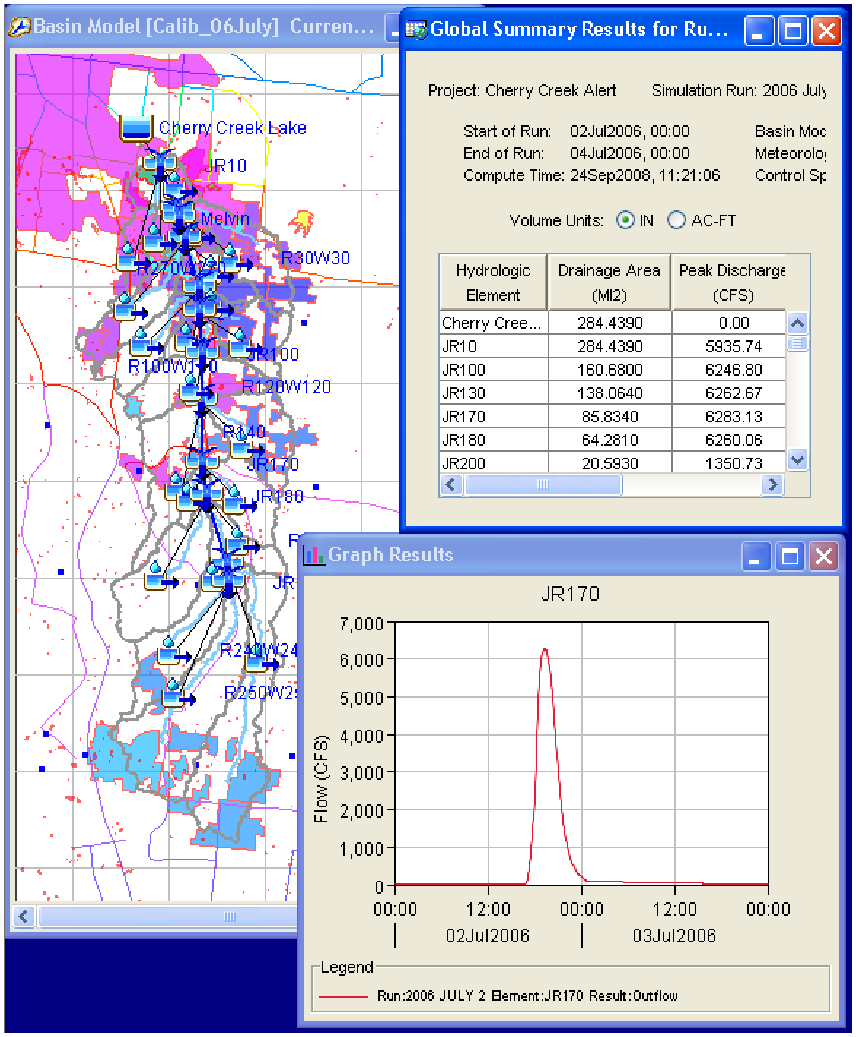
HEC-HMS Modeling Summary:
Cherry Creek Basin Tributary to Cherry Creek Dam

October 2008



Project: Cherry Creek Alert Simulation Run: 2006 Jul

Start of Run: 02Jul2006, 00:00 Basin Moc
End of Run: 04Jul2006, 00:00 Meteorolo
Compute Time: 24Sep2008, 11:21:06 Control Sp

Volume Units: ● IN ○ AC-FT

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)
Cherry Cree...	284.4390	0.00
JR10	284.4390	5935.74
JR100	160.6800	6246.80
JR130	138.0640	6262.67
JR170	85.8340	6283.13
JR180	64.2810	6260.06
JR200	20.5930	1350.73

Run:2006 JULY 2 Element:JR170 Result:Outflow

Prepared by:

U.S. Army Corps of Engineers, Omaha District
Hydrology Section - Hydrologic Engineering Branch
1616 Capitol Avenue
Omaha, NE 68102-9000

Kevin D. Stamm, P.E.

US Army Corps of Engineers ®
Omaha District

For Information Regarding This Document Please Contact:

Kevin Stamm, P.E.
U.S. Army Corps of Engineers, Omaha District
Attention: CENWO-ED-HE
1616 Capitol Avenue
Omaha, NE 68102-9000
(402) 995-2346
kevin.d.stamm@usace.army.mil

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1 GENERAL INFORMATION

1.1 Basin Description

Cherry Creek is a right bank tributary of the South Platte River which enters the river in Denver, Colorado. The Cherry Creek basin contributing drainage area at its mouth is 414 mi^2, and at Cherry Creek Dam it is 385.0 mi^2. The source of Cherry Creek is approximately 57 miles south of its mouth at the Palmer Divide which separates the South Platte and Arkansas River basins. The basin rises in the south to an elevation of 7700 ft and descends to elevation 5190 at its mouth.

1.2 Streamflow Data

Average daily stream discharge was available for Cherry Creek at Franktown, Parker and Melvin, CO, as well as Cherry Creek Lake. Franktown (06712000) and Melvin (06712500) are USGS stream gages that report daily and instantaneous peak discharge, while Parker and Cherry Creek Lake are maintained by the Corps of Engineers. The Melvin gage is no longer in service. The Cherry Creek Reservoir gage is used in combination with gauged lake releases to report daily reservoir inflow, elevation, and storage of Cherry Creek Lake.

During the June 16, 1965, and May 6, 1973, floods, data was collected that enabled the Corps of Engineers to reconstruct flow hydrographs entering Cherry Creek Reservoir. These hydrographs were used along with average daily stream flows to calibrate the hydrologic model.

1.3 Spatial Data

USGS 10-meter grid cell digital elevation data was obtained for the Cherry Creek basin through the USGS Seamless Data clearinghouse. All GIS data was projected into the Standard Hydrologic Grid (SHG) projection, an Albers equal-area projection. SHG projection is referenced with the following spatial information:

Units:	Meters
Datum:	North American Datum, 1983 (NAD83)
1st Standard Parallel:	29 deg 30 min 0 sec North
2nd Standard Parallel:	45 deg 30 min 0 sec North
Central Meridian:	96 deg 0 min 0 sec West
Latitude of Origin:	23 deg 0 min 0 sec North
False Easting:	0.0
False Northing:	0.0

1.4 HEC-HMS

The HEC Hydrologic Modeling System (HMS) simulates the precipitation-runoff process primarily for surface water applications, and computes watershed discharge, storage, and diversions. The model computes runoff through an assortment of soil-water infiltration, runoff transform, and routing methods in a lumped or semi-distributed parameter approach. The Cherry

Creek hydrologic model was created using a lumped parameter approach using the ArcView extension GeoHMS to create basin boundaries, a stream network, and extract basin physical properties from the digital elevation data. Hydrologic model simulations were performed using HEC-HMS version 3.0.1.

2 BASIN MODEL

2.1 Delineations

A total of 22 sub-basins tributary to Cherry Creek Dam were delineated from the 10-meter resolution digital elevation model. Contributing drainage areas along Cherry Creek at gaged locations were 165.9 mi^2 at Franktown, 339.5 mi^2 at the Melvin, and 386.1 mi^2 at Cherry Creek Dam.

2.2 Land Use/Impervious Area

The progression of development within the basin since 1954 was identified and classified using USGS 7.5-minute quadrangle (quad) maps. Development in the years 1954, 1964, and 1988 was determined by identifying urban development and road networks. Aerial photographs from 1999 and 2004 were used to identify development for 2004. Impacts of land use are reflected in the model as sub-basin percent impervious area. The final calibrated model depicts 2004 land use conditions

2.3 Rainfall Losses

The Cherry Creek model uses the Green and Ampt infiltration method along with initial surface storage and canopy losses. The Green and Ampt method was used because it has the ability to simulate variations in initial soil moisture content and changes in soil infiltration rate that occur during a rain storm.

The Green-Ampt Method computes infiltration rate and cumulative infiltration as:

$$f_{t+\Delta t} = K\left(\frac{\Psi\Delta\theta}{F_{t+\Delta t}} + 1\right)$$

$$F_{t+\Delta t} = F_t + K\Delta t + \Psi\Delta\theta \ln K\left[\frac{F_{t+\Delta t} + \Psi\Delta\theta}{F_t + \Psi\Delta\theta}\right]$$

$f_{t+\Delta t}$ = current potential infiltration rate
K = saturated hydraulic conductivity
ψ = soil wetting suction front
$\Delta\theta$ = volumetric moisture deficit
$F_{t+\Delta t}$ = cumulative infiltration
F_t = cumulative infiltration at the previous time step.

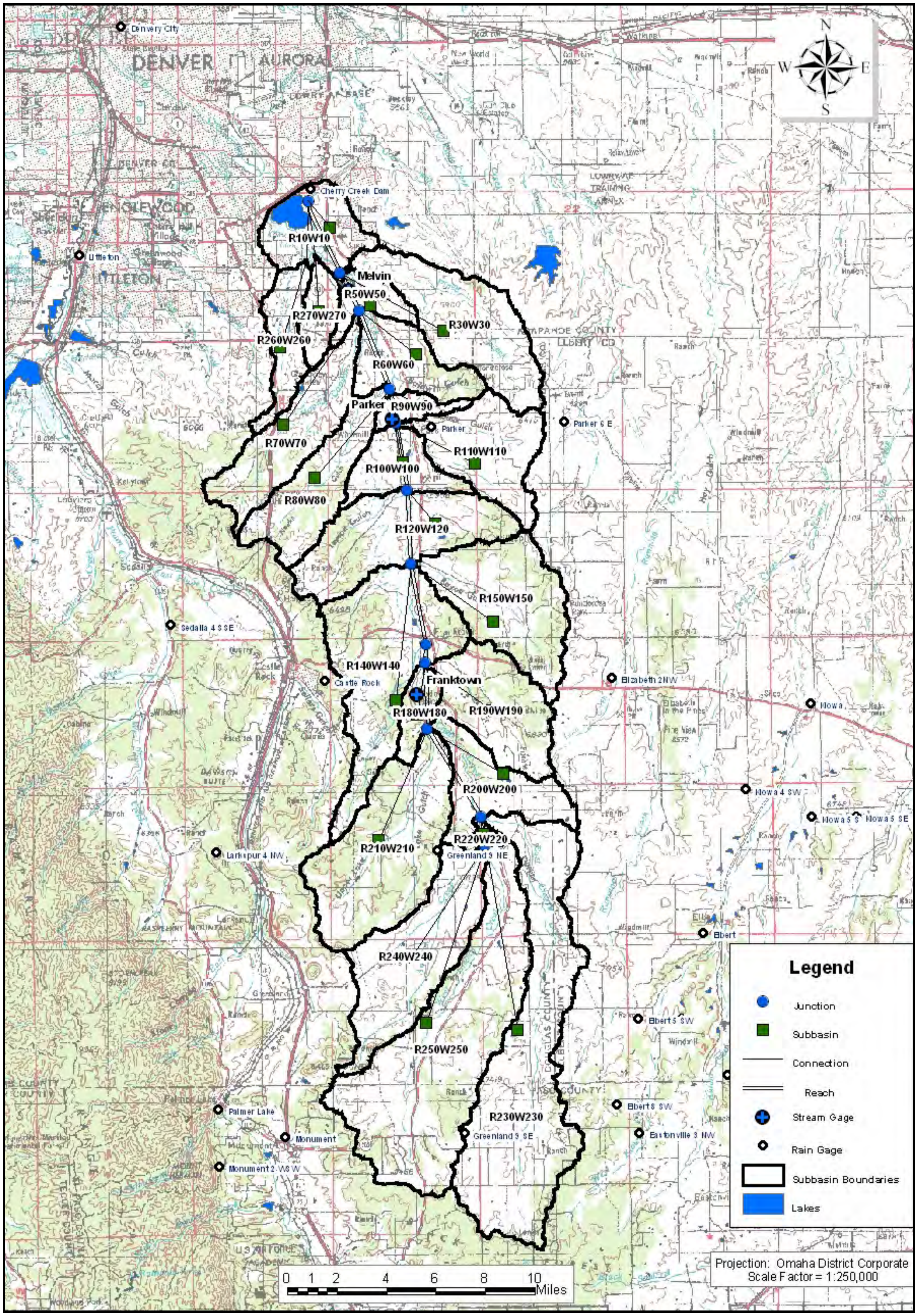

Figure 1. Cherry Creek Basin HEC-HMS model tributary to Cherry Creek Lake.

Potential infiltration rate (f) and cumulative infiltration (F) are functions of F and the hydrologic parameter constants $\Delta\theta$, Ψ, and K, specified within the model. K defines the rate which water moves through the soil when the soil is saturated, and it is not equivalent to the infiltration rate. Ψ is a soil physical property that defines the soil pressure or tension usually as a function of soil dryness. Volumetric moisture deficit ($\Delta\theta$) is the soil pore volume free of water, and it is dependent on the soil porosity and water content. Effective porosity was used as $\Delta\theta$ for dry soil (Rawls et. al, 1982), and a reduced $\Delta\theta$ was computed for wetter soils at field capacity. Field capacity is a condition of the soil in which a saturated soil is allowed time to sufficiently drain, and the soil tension is at -0.33 bars of pressure. Field capacity $\Delta\theta$ was based on standard values cited in Schwab, et al. (1993).

From the equation for f, initial f is near infinity because F is near zero, but as F increases, f approaches K. Infiltration occurs at a rate equal to the rainfall rate (i) if f is less than i. When i exceeds f, infiltration occurs at the rate of f, and F is computed with the specified Green-Ampt equation.

Green and Ampt parameters required by HEC-HMS include volumetric moisture deficit (θ), wetting suction (Ψ) front, and saturated hydraulic conductivity (K). Sub-basin averaged Green and Ampt parameters were determined by combining standard parameter values associated with soil texture (Rawls et. al., 1982) to a GIS overlay of Cherry Creek sub-basins and soil textural classes. Field capacity soil loss parameters and unit graph parameters for individual sub-basins are provided in Table 1. Green and Ampt soil loss parameters used in the calibration of flood hydrographs for the 1965, 1973, and 2006 discharge events are provided in Tables 2 – 4.

2.4 Transform Method

The Clark's synthetic unit hydrograph method was chosen for this model in order to provide the capability of using gridded time-series precipitation data in the Corps Water Management System (CWMS) at a later time. Clark's method in HEC-HMS uses a smooth function fitted to a typical time-area relationship in which only the basin time of concentration, t_c, and the storage coefficient, R, are specified in the model. A storage coefficient of 1.0 worked well in the calibration simulations.

2.5 Channel Routing

The Muskingum-Cunge routing method was used to route sub-basin discharges through the Cherry Creek channel to Cherry Creek Lake. Eight-point channel cross sections were extracted from the 10-meter digital elevation model of Cherry Creek basin using GeoRAS. Roughness coefficients for the channel and overbank areas of 0.03 and 0.05, respectively, were set during the model calibration. Observation of some streamflow data indicated that channel infiltration caused a significant volume of water to be lost from Cherry Creek; however, this phenomenon was not modeled in this particular version of the Cherry Creek model.

Table 1. Soil loss parameters at field capacity and HMS transform parameters model sub-basins.

Sub-basin	Initial Loss (Inches)	Volumetric Moisture Deficit	Wetting Suction Front (inches)	Saturated Hydraulic Conductivity (in/hr)	Time of Concentration (hrs)	Clark's Storage Coefficient (R)
R100W100	0.2	0.21	10.4	0.31	2.16	1
R10W10	0.2	0.13	15.1	0.23	2.68	1
R110W110	0.2	0.24	8.6	0.36	2.72	1
R120W120	0.2	0.22	9.6	0.33	2.46	1
R140W140	0.2	0.21	10.5	0.31	5	2.5
R150W150	0.2	0.22	10.0	0.32	3.10	1
R180W180	0.2	0.22	9.3	0.34	1.53	1
R190W190	0.2	0.22	10.0	0.32	2.79	4
R200W200	0.2	0.17	13.0	0.26	3.48	1
R210W210	0.2	0.20	10.1	0.28	5.4	4
R220W220	0.2	0.17	13.4	0.25	0.84	1
R230W230	0.2	0.20	10.0	0.28	9.08	4
R240W240	0.2	0.21	9.6	0.28	5.98	4
R250W250	0.2	0.21	9.5	0.28	7.9	4
R260W260	0.2	0.17	13.3	0.25	2.92	1
R270W270	0.2	0.18	12.7	0.27	2.29	1
R30W30	0.2	0.21	10.7	0.32	4.19	1
R50W50	0.2	0.24	8.8	0.35	1.67	1
R60W60	0.2	0.23	9.2	0.33	2.82	1
R70W70	0.2	0.20	11.3	0.30	3.78	1
R80W80	0.2	0.19	12.1	0.28	3.33	1
R90W90	0.2	0.21	9.7	0.31	1.69	1

Table 2. Green and Ampt soil parameters calibrated for the June 16, 1965 flood event.

Sub-basin	Initial Loss (Inches)	Volumetric Moisture Deficit	Wetting Suction Front (inches)	Saturated Hydraulic Conductivity (in/hr)
R100W100	0.2	0.20	10.0	0.31
R10W10	0.2	0.13	14.6	0.23
R110W110	0.2	0.23	8.2	0.36
R120W120	0.2	0.21	9.2	0.33
R140W140	0.2	0.20	10.1	0.31
R150W150	0.2	0.21	9.6	0.32
R180W180	0.2	0.21	8.9	0.34
R190W190	0.2	0.21	9.6	0.32
R200W200	0.2	0.16	12.6	0.26
R210W210	0.2	0.19	9.7	0.28
R220W220	0.2	0.16	13.0	0.25
R230W230	0.2	0.19	9.6	0.28
R240W240	0.2	0.20	9.2	0.28
R250W250	0.2	0.20	9.1	0.28
R260W260	0.2	0.16	12.9	0.25
R270W270	0.2	0.17	11.9	0.27
R30W30	0.2	0.20	10.3	0.32
R50W50	0.2	0.23	8.4	0.35
R60W60	0.2	0.22	8.8	0.33
R70W70	0.2	0.19	10.9	0.30
R80W80	0.2	0.18	10.7	0.28
R90W90	0.2	0.20	9.3	0.31

Table 3. Green and Ampt soil parameters calibrated for the May 6, 1973 flood event.

Sub-basin	Initial Loss (Inches)	Volumetric Moisture Deficit	Wetting Suction Front (inches)	Saturated Hydraulic Conductivity (in/hr)
R100W100	0.2	0.01	2.8	0.31
R10W10	0.2	0.01	4.5	0.23
R110W110	0.2	0.01	2.0	0.36
R120W120	0.2	0.01	2.3	0.33
R140W140	0.2	0.01	2.7	0.31
R150W150	0.2	0.01	2.5	0.32
R180W180	0.2	0.01	2.1	0.34
R190W190	0.2	0.01	2.5	0.32
R200W200	0.2	0.01	4.5	0.26
R210W210	0.2	0.01	3.1	0.28
R220W220	0.2	0.01	4.7	0.25
R230W230	0.2	0.01	3.0	0.28
R240W240	0.2	0.01	2.8	0.28
R250W250	0.2	0.01	2.8	0.28
R260W260	0.2	0.01	4.1	0.25
R270W270	0.2	0.01	3.7	0.27
R30W30	0.2	0.01	2.8	0.32
R50W50	0.2	0.01	2.0	0.35
R60W60	0.2	0.01	2.1	0.33
R70W70	0.2	0.01	3.2	0.30
R80W80	0.2	0.01	3.5	0.28
R90W90	0.2	0.01	2.4	0.31

Table 4. Green and Ampt soil parameters calibrated for the July 2, 2006 flood event.

Sub-basin	Initial Loss (Inches)	Volumetric Moisture Deficit	Wetting Suction Front (inches)	Saturated Hydraulic Conductivity (in/hr)
R100W100	0.2	0.21	10.4	0.31
R10W10	0.2	0.13	15.1	0.23
R110W110	0.2	0.24	8.6	0.36
R120W120	0.2	0.22	9.6	0.33
R140W140	0.2	0.21	10.5	0.31
R150W150	0.2	0.22	10.0	0.32
R180W180	0.2	0.22	9.3	0.34
R190W190	0.2	0.22	10.0	0.32
R200W200	0.2	0.17	13.0	0.26
R210W210	0.2	0.20	10.1	0.28
R220W220	0.2	0.17	13.4	0.25
R230W230	0.2	0.20	10.0	0.28
R240W240	0.2	0.21	9.6	0.28
R250W250	0.2	0.21	9.5	0.28
R260W260	0.2	0.17	13.3	0.25
R270W270	0.2	0.18	12.7	0.27
R30W30	0.2	0.21	10.7	0.32
R50W50	0.2	0.24	8.8	0.35
R60W60	0.2	0.23	9.2	0.33
R70W70	0.2	0.20	11.3	0.30
R80W80	0.2	0.19	12.1	0.28
R90W90	0.2	0.21	9.7	0.31

3 FLOOD CONTROL STORAGE

3.1 Sub-basin Impoundments

The National Inventory of Dams lists 41 flood control structures in the Cherry Creek drainage basin, 26 located upstream of the Franktown, CO, stream gage; and, 15 located downstream of the Franktown gage. These structures delay the runoff hydrograph peak discharge by storing water behind the impoundments. In the hydrologic model flood control structures impact sub-basins upstream of Cherry Creek Lake. The main basin model does not incorporate the flood control structures, but compensates for runoff storage and the lag in time of peak discharge through modified Clark storage coefficients (Table 5) and lagging of times of peak discharge.

Table 5. Modeled sub-basins that contain unit graph parameters adjusted for watershed flood storage.

Sub-basin	*R*	% of Controlled Area	Flood Storage ac ft
R140W140	2.5	34.6	618
R190W190	4.0	54.7	767
R210W210	4.0	54.4	1016
R230W230	4.0	79.6	2871
R240W240	4.0	85.0	1427
R250W250	4.0	87.1	2042

3.2 Cherry Creek Dam

Cherry Creek Dam engineering data is listed below in Table 6.

Table 6. Cherry Creek Engineering Data.

Dam Embankment		**Reservoir Elev. and Area**	
Top of dam, ft MSL	5644.5	Maximum Pool, ft MSL	5645.0
Length of Dam, ft	14,300	Top of flood control pool	5608.7
Height of Dam, ft MSL	141	Top of multipurpose pool	5550.0
Stream bed, ft MSL	5504.0		
Spillway		**Outlet Works**	
Crest elevation, ft MSL	5598.0 (design)	Number and size	2 – 8 x 12 ft. oval conduits
	5608.7 (flood control)		1 – 12 ft. circular conduit
	5610.6 (2008 condition)	Length, ft	679.5 ft
Design width, ft MSL	67	Discharge capacity, cfs	8100 at 5598.0 ft MSL

3.3 Elevation-Storage Functions

Over the life of Cherry Creek Dam the volume of permanent and flood control storage has changed due to major runoff events; therefore, several reservoir-elevation-capacity curves are used in the hydrologic model. The model contains reservoir elevation-storage functions based on bathymetric surveys conducted in 1950, 1961, 1965, and 1988. Functions from 1961, 1965 and 1988 are plotted in Figure 2. The 1988 curve reflects the most recently surveyed lake bathymetry.

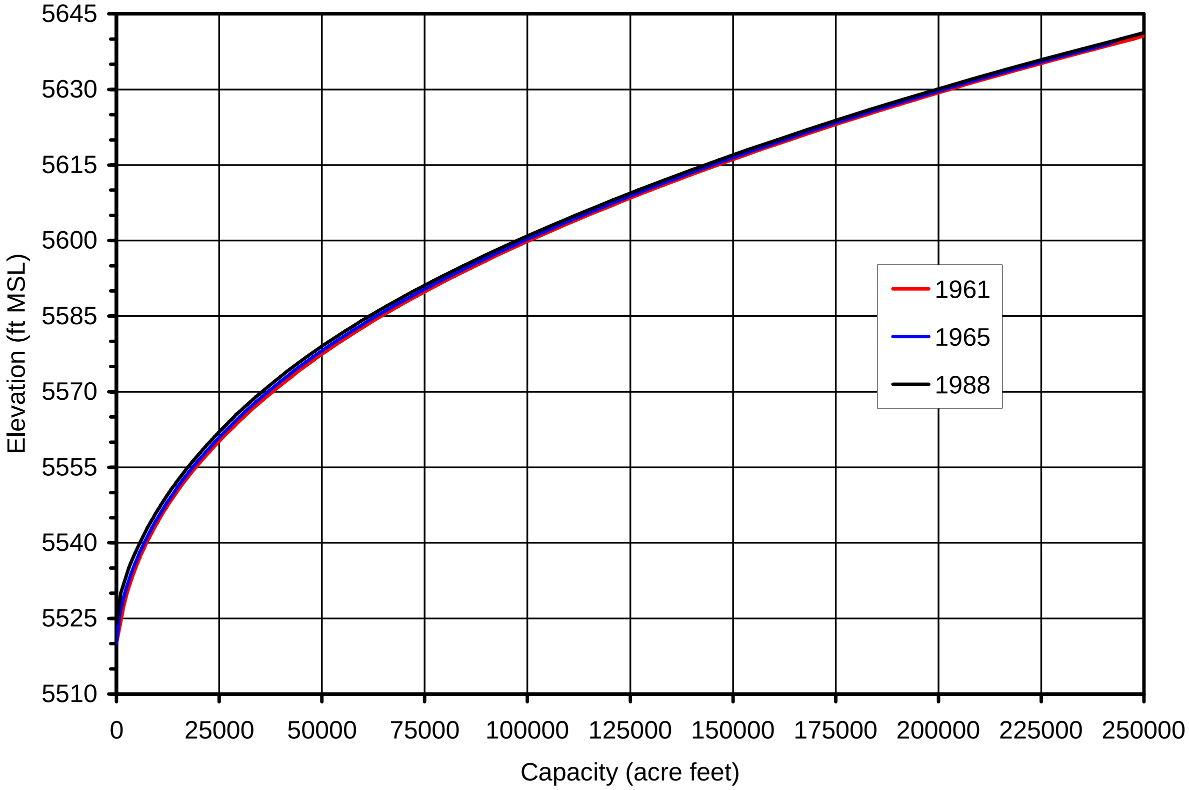

Figure 2. Cherry Creek elevation-capacity derived from the 1961, 1965, and 1988 bathymetric surveys.

3.4 Spillway Rating

The Cherry Creek spillway was originally designed and constructed with a crest elevation of 5598 ft MSL and a bottom width of 67 feet with side slopes ranging from one (horizontal) on two (vertical) to one on one. The spillway was designed using a Manning's roughness coefficient (n) of 0.025 for velocity limitations and 0.035 for spillway capacity. Over time the poor stability of the slopes caused sloughing toward the bottom of the spillway, effectively raising the crest elevation to 5608.7 ft MSL. In addition a lack of maintenance has allowed thick shrubs and some trees to grow in the spillway raising estimated channel coefficients to 0.075 and side slope coefficients to 0.065. The reservoir regulation manual specifies 5608.7 ft MSL as the top of the flood control pool and crest of the spillway channel; however, the April 2008 survey determined the crest elevation was near 5610.6 ft MSL with a rating curve reflecting the existing channel roughness conditions. The three crest elevation rating curves plotted in Figure 3 are for the design condition (5598.0 ft MSL), an improved channel condition with lower roughness (5608.7 ft MSL), and the existing channel condition (5610.6 ft MSL).

The hydrologic model includes discharge rating curves for the 5608.7 ft MSL crest elevation in its existing condition (EC), the 5608.7 ft MSL crest elevation in an improved condition (IC), and the 5610.7 ft MSL crest elevation in its existing condition (EC). Additional rating curves include discharge due to dam overtopping (OT) and outlet works (OW) discharge limited to 5000 cfs.

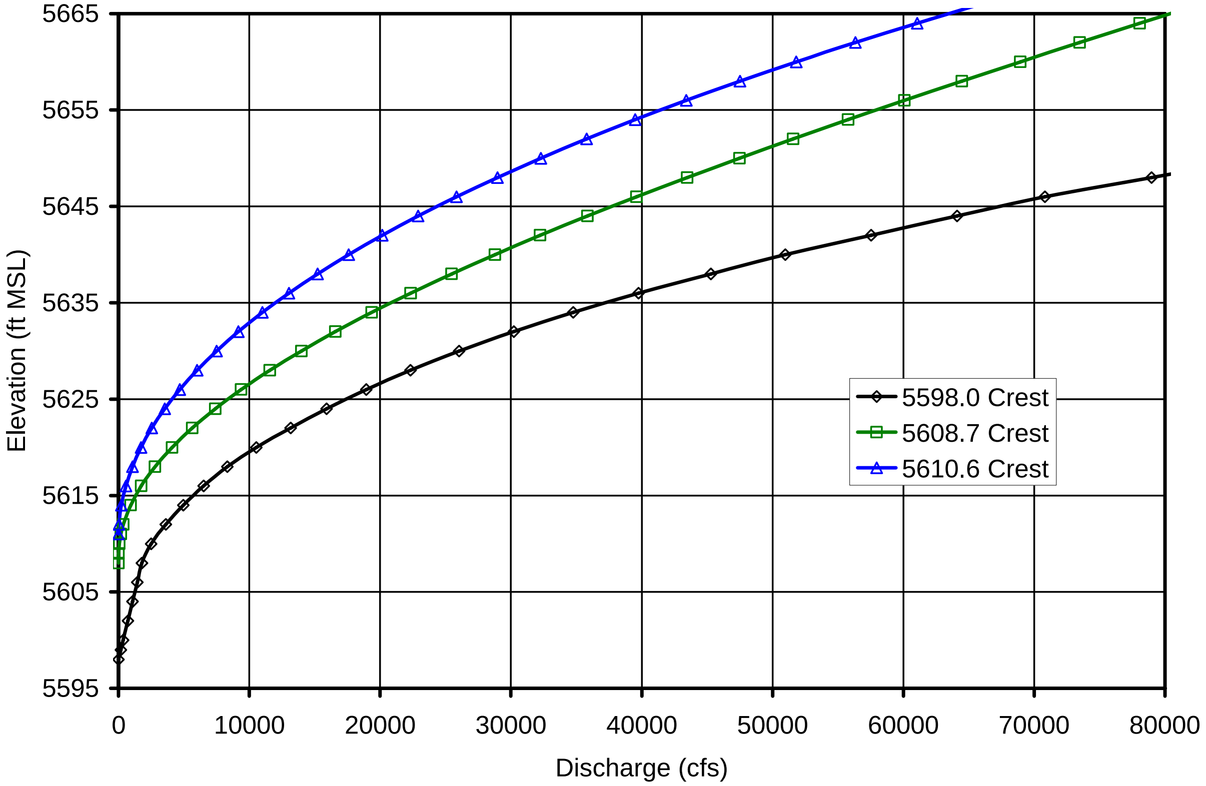

Figure 3. Cherry Creek spillway rating curves for the designed spillway, 2008 existing condition and the improved channel condition.

4 METEOROLOGIC MODELS

4.1 User-Specified Hyetographs

User-specified hyetograph precipitation methods were used for Cherry Creek calibration floods which included the June 16, 1965 storm; May 5, 1973 storm; and the July 2, 2006 storm. User-specified hyetographs are rainfall hyetographs specified for individual sub-basins. Complete hyetograph information is included in the HEC-HMS meteorologic model files.

4.2 Inverse-Distance Precipitation Events

Inverse-distance meteorological models represent rainfall events by weighing rain gage precipitation by the inverse of the distance from the gage to the sub-basin centroid. This method works relatively well if the watershed contains a good network of rain gages. The hydrologic model contains meteorological models for the August 3, 1963; and July 23, 1983 storms.

5 MODEL SUMMARY

Table 7 summarizes the basin models, meteorological models, and simulations that the Cherry Creek HEC-HMS model contains. The basin models are all based on the same sub-basin delineations, unit graph parameters, and channel properties; but, they differ in initial soil conditions. Both inverse-distance and user-specified hyetograph meteorologic models are contained within the model files. The model was calibrated using primarily user-specified hyetographs for the 1965, 1973, and 2006 runoff events. Finally the model is configured to perform five simulations. The Cherry Creek Calibrated basin model was not used in a simulation, yet it contains baseline soil moisture parameters from which most simulations can be initiated.

Table 7. HEC-HMS model basin, meteorologic, and simulation components for Cherry Creek Basin.

Basin Model	**Description**	
Cherry Creek Calibrated	Baseline model with 2004 imperviousness, field capacity soil parameters, and calibrated Clark parameters	
Calib_06July	Cherry Creek Calibrated model, soil parameters adjusted for 2006 storm	
Calib_63	Cherry Creek Calibrated model, soil parameters adjusted for 1963 storm	
Calib_65	Cherry Creek Calibrated model, soil parameters adjusted for 1965 storm	
Calib_73	Cherry Creek Calibrated model, soil parameters adjusted for 1973 storm	
Calib_88	Cherry Creek Calibrated model, soil parameters adjusted for 1988 storm	
Meteorologic Model	**Storm Type**	**Data Source**
1963Aug3-7	inverse-distance	NCDC
1965Jun16_COE	user-specified hyetograph	COE data
1965Jun16_USGS_Calib	user-specified hyetograph	USGS publication
1973May6_Calib	user-specified hyetograph	USGS publication
1983Jul21-24	inverse-distance	NCDC
2006 July 2 #1	user-specified hyetograph	Urban Drainage
Simulation	**Basin Model**	**Meteorologic Model**
1963Aug3-7	Calib_63	1963Aug3-7
1965Jun16_Calib	Calib_65	1965Jun16_USGS_Calib
1973May5_Calib	Calib_73	1973May6_Calib
1983July22-25	Calib_88	1983Jul21-24
2006July2	Calib_06July	2006 July 2 #1

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