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INNOVATIVE DESIGN APPROACHES FOR THE SOUTH PLATTE RESERVOIR

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ABSTRACT

The proposed South Platte Reservoir is a 6,400 acre-foot municipal raw water storage facility located in an urbanized area of the southwest Denver metropolitan area. The reservoir will supply raw water to the rapidly growing Highlands Ranch development. South Platte Reservoir has been designed as off-stream storage. The major tributary to South Platte Reservoir flows eastward toward the South Platte River, through a residential area. Instead of routing the runoff through the reservoir, a bypass flood channel has been designed to carry runoff from the Probable Maximum Precipitation (PMP) around the north side of the reservoir and discharge the flows safely to the South Platte River below the site. Normal base flows, as well as small storm flows will be typically routed around the reservoir in this channel. A diversion structure is planned, however, that will allow for diversion of low flows into the reservoir as desired.

This innovative design for the reservoir will significantly reduce the size, cost, and impact of the reservoir's spillway. Also, the bypass channel consisting of a low-flow channel meandering through wetlands grasses and shrub willow plantings will become a prominent habitat feature of the project.

Another innovative aspect of the overall project involved a site specific PMP study for the small-area project drainage. The drainage is located on the high plains near the foothills of the eastern slope of the Rocky Mountains southwest of Denver, but it is isolated from mountain runoff. This circumstance led to detailed consideration of local orographic effects on precipitation intensity and distribution, i.e., storm centering. The site specific PMP study underwent peer review and has been accepted by the Colorado Office of the State Engineer (SEO). Compared to Hydrometeorological Report - HMR 55A, the standard reference used by the State to estimate the PMP in this region, the site specific study results reduced the project area general storm PMP values by 28 percent at 1 hour duration and 14 to 15 percent at durations from 6 to 72 hours. Local storm values were reduced by 22 to 23 percent at all durations. The design capacity of the bypass channel was reduced from 50,000 cfs to 22,000 cfs as a result of these reductions. As a result of the reduced bypass channel dimensions, the storage capacity of the reservoir was increased by approximately 100 acre-feet. The value of the construction cost savings and storage capacity increase was in excess of $1,000,000.

1.0 INTRODUCTION

The proposed South Platte Reservoir (SPR) is a 6,400 acre-foot municipal raw water storage facility located in an urbanized area of the southwest Denver metropolitan area. The reservoir will supply raw water to the rapidly growing Highlands Ranch development. South Platte

Reservoir has been designed as off-stream storage. The major tributary to the South Platte Reservoir flows eastward toward the South Platte River, through a residential area. Instead of routing the runoff through the reservoir, a bypass flood channel has been designed to carry runoff from the PMP around the north side of the South Platte Reservoir and discharge flows safely to the South Platte River below the site as shown on Figure 1. A site specific PMP study was conducted for the small-area project drainage.

2.0 PROJECT DESCRIPTION

Based on the maximum height of the dam (approximately 40 feet) and the capacity of the dam at the spillway crest (approximately 6,400 acre-feet), South Platte Reservoir Dam would be classified as an intermediate-sized dam. Because loss of human life would be possible from a dam break, a Class I hazard rating would be appropriate. A new Class I, intermediate-sized dam would be required by the Colorado Office of the State Engineer to have an emergency spillway large enough to accommodate the runoff associated with the PMP. If a bypass channel would be constructed to reduce the amount of the PMP runoff entering the reservoir, it should be sized to eliminate the necessity for flood easements on adjacent properties and should provide adequate protection of the dam embankment if the dam embankment would be an integral part of the bypass channel.

3.0 SITE SPECIFIC PROBABLE MAXIMUM PRECIPITATION DETERMINATION

The methodology used in this site specific PMP study hinges on the historic extreme storm data base representing a large region along and adjacent to the Front Range of the Rockies. A collection of approximately twenty historic storms, from locations as distant as Montana, was distilled from a comprehensive storm search which encompassed the various HMR's, the Colorado Extreme Storm Precipitation Data Study, NOAA's Storm Data publications and other PMP investigations within the region. For these historic storms, their meteorological setting and characteristics were carefully analyzed to determine whether each could have occurred over the project area. Some of the more (in)famous historic storms used in this study include: for the general storm, Big Thompson, CO (1976), Gibson Dam, MT (1964), Fort Collins, CO (1997), Kiowa/Hale/Cherry Creek, CO (1935), Plum Creek, CO (1965) and Savageton, WY (1923), and for the local storm, Cheyenne, WY (1985) and Colorado Springs, CO (1985).

3.1 PMP Storm Types

Warm season extreme storms over the region can be of various types, including a) convective systems, both simple, e.g., local (thunder)storms and complex, e.g., general storms consisting of organized groups of convective storms, manifested at the extreme end of the convective storm spectrum by the mesoscale convective complex, and b) extratropical cyclonic/frontal systems, especially when they contain embedded convective elements. These categories are somewhat idealized, with many storms exhibiting combinations of characteristics of the individual storm types. However, the most extreme storm events share some common characteristics. One of those common characteristics is the availability of broad scale, sustained, very moist, and unstable air in the lower atmosphere. This is invariably supported by easterly-component low level flow of marine (primarily Gulf of Mexico) origin, initially supplied by anti-cyclonic flow around the Bermuda high and usually further supported by the cyclonic wind circulation around a low pressure center south of the rainfall area. These circulation features combine to transport the very moist air masses from the Gulf across the plains, and then to provide an easterly-component trajectory into the region adjacent to the foothills and higher terrain of the Rockies. The most extreme storms are also often associated with a weak and/or stationary front to the west and north of the heaviest precipitation region. Depending on the exact locations and strength of the Bermuda high, the low pressure center and the more-local surface fronts, the warm, moist southeasterly to easterly winds along the Front Range in the lower atmosphere interact with both the atmospheric dynamics and the topography to produce large rainfall events. All of the most extreme historic storms exhibit strong convective characteristics, with the pronounced vertical motion associated with heavy precipitation further supported by very cold air aloft which enhances atmospheric instability.

3.2 Watershed Characteristics and Regional Topography

An analysis was performed regarding the geographic distribution of the most significant historic storm rainfall centers which have occurred in the region from the vicinity of Pueblo northward to the Wyoming border. This analysis shows very distinct clustering of the precipitation centers along the foothills of the Front Range and the Palmer Divide, an important terrain feature oriented east-west between Denver and Colorado Springs, demonstrating the importance of the "orographic" influence on the production of extreme rainfalls and the locations of those maximum rainfalls. In Colorado, the Front Range foothills and the Palmer Divide are the first abrupt increases or "upslopes" in terrain height encountered by air masses which carry rich moisture from the Gulf of Mexico advected westward across the high plains. These barriers are analogous to the first barrier effects in coastal or near-coastal mountain areas. The presence of this orographic "trigger" mechanism as an additional source of vertical motion is crucial to regional production and distribution of the most extreme rainfalls.

The project drainage is located on the high plains east of the foothills of the eastern slope of the Rockies. It is isolated from mountain runoff. In light of the crucial role of orographic influences regarding precipitation production and the location of orographically-enhanced rainfall centers, the project drainage location led to detailed consideration of local orographic effects on precipitation intensity and distribution, i.e., storm centering. This study considered the orographic influence of the foothills to the west of the SPR drainage basin in light of the low level moisture flow required for the region's most extreme storms, and concluded that the significant influence on the extreme rainfall storms would be focused over the foothills and mountains. Such (orographic) storms over the nearby mountains can produce significant "edge effect" rainfalls over the SPR drainage, but less than would be produced by non- or least-orographic storms which could be _centered_ directly over the drainage basin. The significance of this conclusion is that, a) when transpositioning historic extreme storms, the storm types which exhibited significant in-place orographic influences must be centered over similar terrain, in this case the foothills or mountains west of the SPR drainage basin, and b) that historic storms within meteorological transposition limits not exhibiting substantial in-place orographic influences ("least orographic" storms in the HMR) can be centered over the drainage basin to provide the maximum possible volume and rates.

3.3 PMP Study Procedures

3.3.1 General Storm

The most extreme of the relevant general storms were moved (transpositioned) to or near the project area and maximized according to regional moisture climatologies, to estimate their potential precipitation production under worst case (most severe) scenarios. The maximization procedures used in the site specific study are consistent with those used in development of the HMR's. The in-place maximization factor for each general storm was reviewed. Modifications to the maximization factors were applied to centers within the 1935 Colorado and 1964 Montana storms, based on re-analysis of surface dew point data. Each of several of the greatest non-orographic and orographic storms was centered appropriately over or near the project drainage. Non-orographic rainfall centers were critically located directly over the project site, while the orographic rainfall centers were transpositioned to the terrain immediately adjacent to the project site, exercising great care to as closely as possible emulate each historic storm's in-place orographic character. Examples are shown in Figure 2.

Depth-duration curves derived from the set of isohyetal patterns resulting from the maximized and transpositioned storms were constructed and the composite family of curves, shown in Figure 3, was then enveloped to determine the site specific warm season general storm PMP at various durations for the project area.

3.3.2 Local Storm

Many of the local storms appearing in historic storm lists clearly include orographic influences. Since the project drainage is considered to be in a non- or least-orographic location, the local storm search was limited to storms without orographic influence because the maximized and transpositioned isohyetal patterns associated with orographically centered local storms would have minimal impact over the South Platte Reservoir drainage due to their compact dimensions and sharp rainfall gradients. The site specific local storm PMP was developed using the largest non-orographic local storm in the historic record, the Cheyenne, WY storm of 1985, as its basis. This storm, with an official rainfall observation of 6.06 inches and an unofficial report of 7.0 inches, both in three hours, resulted in 12 deaths, severe flooding and $65 million in damage. A large maximization factor of 1.50 was applied and, because of its non-orographic nature, it was centered directly over the project drainage. Applying the local storm temporal and depth-area relations shown in HMR 55A, the unofficial 7 inch (3 hr) point rainfall value was maximized and used as the basis for the incremental site specific PMP values from 0.25 hours to 6 hours duration.

3.4 Site Specific PMP Study Results

The site specific general storm and local PMP values for the South Platte Reservoir drainage as determined in this study are shown in Table 1. Since the site specific PMP study has been accepted by the State Engineer's Office (SEO) in Colorado, these values supercede those derived for SPR using HMR 55A, which also appear in the Table for reference.

Table 1.

South Platte Reservoir Site Specific PMP Depth-Duration (inches)

General Storm

	1 hr	3 hr	6 hr	9 hr	12 hr	24 hr	72 hr
Site Specific	***10.9***	***13.6***	***22.8***	***27.8***	—	***29.6***	***35.2***
HMR 55A	15.2	---	26.5	---	---	34.5	41.2

Local Storm

	0.25	0.5	0.75	1 hr	2 hr	3 hr	4 hr	5 hr	6 hr
Site Specific	***5.0***	***6.5***	***7.2***	***7.8***	***9.1***	***9.8***	***10.2***	***10.6***	***10.9***
HMR 55A	6.4	8.4	9.2	10.0	11.8	12.6	13.1	13.6	14.0

The site specific study results reduce the project area general storm PMP values by 28 percent at 1 hour duration and by 14 to 15 percent at durations from 6 to 72 hours. Local storm values were reduced by 22 to 23 percent at all durations. The differences between the site specific study values and those in HMR 55A are largely attributable to storm centering precisions, i.e., distinction between orographic and non- or least orographic storms and differences in the geographic area over which orographic influences are considered effective.

4.0 HYDROLOGIC ROUTING OF THE PMP

The proposed location for the South Platte Reservoir is south of the confluence of two drainage channels. They are commonly known as 7-11 Gulch and the North Tributary of 7-11 Gulch. The drainage area contributing runoff to the South Platte Reservoir and the bypass channel is approximately 4.5 square miles. The major channel, 7-11 Gulch, contributes approximately 3.2 square miles of the drainage area and has a slope of approximately 2 percent. Currently, the watershed is approximately 90 percent developed and is anticipated to approach 95 percent in the future.

4.1 Inflow Design Flood for the South Platte Reservoir

The Inflow Design Flood (IDF) for the South Platte Reservoir would not be the entire runoff hydrograph from the watershed because of the construction of the bypass channel. West of the project, the PMP runoff from 7-11 Gulch would overtop South Platte Canyon Road before flowing into either the South Platte Reservoir or the bypass channel. The dam embankment that forms the south bank of the bypass channel would be extended westward toward South Platte Canyon Road, dividing the flow that would overtop South Platte Canyon Road. The portion of the flow that overtops the road south of this divide enters the reservoir while the remainder enters the bypass channel.

The peak flow rate of the general storm site specific PMP runoff would be 24,000 cfs upstream of South Platte Canyon Road. The component of the 7-11 Gulch hydrograph that flows into South Platte Reservoir has a peak flow rate of 7,000 cfs. Combining this hydrograph with minor subbasins in the vicinity of the reservoir and direct precipitation on the reservoir would produce an IDF with a peak flow rate of 12,000 cfs. The remainder of the divided flow hydrograph with a peak flow rate of 17,000 cfs would enter the bypass channel.

The runoff from both general and local storms were analyzed and it was determined that the general storm controls the sizing of the emergency spillway and the bypass channel.

4.2 Design Flood for the Bypass Channel

South Platte Reservoir would have five feet of freeboard between the dam crest and the emergency spillway. The runoff from the PMP storm that would enter South Platte Reservoir must safely pass through the reservoir with a minimum residual freeboard of one foot. A surcharge of approximately 610 acre-feet would be provided in the four feet above the emergency spillway crest. A trapezoidal spillway with a bottom width of 175 feet and 10H:1V side slopes is proposed. Outflow from the emergency spillway would be discharged to the upper reach of the bypass channel approximately 1,000 feet downstream of South Platte Canyon Road. Combining the runoff that overtopped South Platte Canyon Road and flowed into the bypass channel with the spillway outflow would result in a hydrograph with a peak flow rate of 20,000 cfs. Utilizing the available detention storage in South Platte Reservoir has reduced the design flow rate in the upper portion of the bypass channel by approximately 20 percent from 24,000 cfs to 20,000 cfs.

Approximately 1,500 feet downstream of South Platte Canyon Road, the runoff from the North Tributary of 7-11 Gulch combines with the flow in the bypass channel. Downstream of this confluence, the design flow rate for the remainder of the bypass channel is increased to 22,000 cfs.

4.3 Design Concept for HMR 55A PMP

The runoff hydrograph produced by the HMR 55A PMP storm would have a peak flow rate of 39,000 cfs upstream of South Platte Canyon Road. The concept of dividing the flow and allowing a portion to enter the reservoir is suitable for the volume of runoff from the site specific PMP relative to the available surcharge storage in the reservoir. However, it would not be practical to pursue this concept with the runoff hydrograph produced by the HMR 55A PMP storm. A much larger emergency spillway would be required and the time to the peak of the spillway outflow would not be lagged significantly from the peak flow in the bypass channel. Thus, the reservoir design for the HMR 55A PMP storm would be essentially a ring dike and the bypass channel would be designed to convey the entire 39,000 cfs in the upper reach and 50,000 cfs in the lower reach.

5.0 BYPASS CHANNEL DESIGN

Normal base flows, as well as small storm flows will be typically routed around the reservoir in a bypass channel approximately 3,300 feet in length. A diversion structure is planned, that will allow for diversion of low flows from 7-11 Gulch into the reservoir as desired. The bypass channel consisting of a low-flow channel meandering through wetland grasses and shrub willow plantings will become a prominent habitat feature of the project.

The bypass channel will have a 100-foot bottom width with 3H:1V side slopes. The bed slope of the channel would be 0.005 between grouted boulder drop structures. The bottom of the channel will be vegetated with shrub willow plantings and wetland grasses with a dryland grass mix on the side slopes. A low flow channel approximately 4 feet in depth with a 1¼-year return period capacity will meander across the bottom of the channel. Channel maintenance will consist of pruning willows to a diameter of 3 inches or less. During the routing of the PMP design flood, the water surface elevation in the bypass channel would be approximately 14 to 16 feet above the invert of the low flow channel.

6.0 CONCLUSIONS

The site specific PMP study resulted in significant cost savings in the bypass channel, drop structures, diversion structure, and the emergency spillway. The design flow rate was reduced from 39,000 cfs to 20,000 cfs in the upper reach and from 50,000 cfs to 22,000 cfs in the lower reach. The depth of the bypass channel was reduced by about 8 feet and the top width was reduced by about 50 feet. As a result of these reduced bypass channel dimensions, the storage capacity of the reservoir was increased by approximately 100 acre-feet. The value of the construction cost savings and storage capacity increase was in excess of $1,000,000.

Site specific PMP studies conducted for other eastern slope high plains watershed with similar positions relative to the Front Range in Colorado, especially north of the Palmer Divide, as well as in Wyoming and Montana, can potentially provide PMP design values reduced from those derived using HMR 55A. The results will vary among individual basins, depending on basin size and elevation, plus their locations relative to orographic barriers and the transposition limits of the largest storms which comprise the historical extreme storm record. Acceptance of the South Platte Reservoir site specific study by the State of Colorado and a similar study conducted by the authors for another reservoir in the region are important precedents.

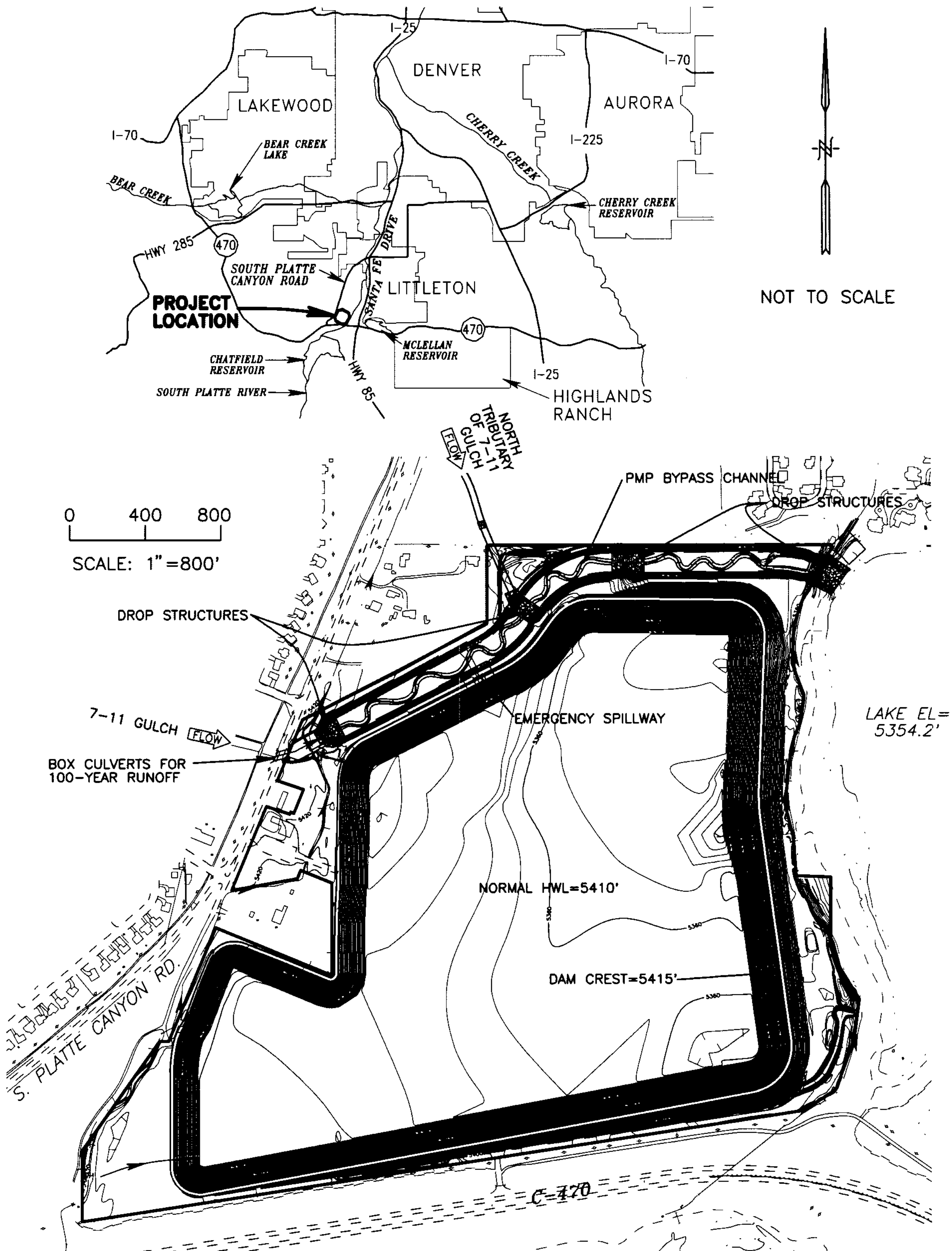
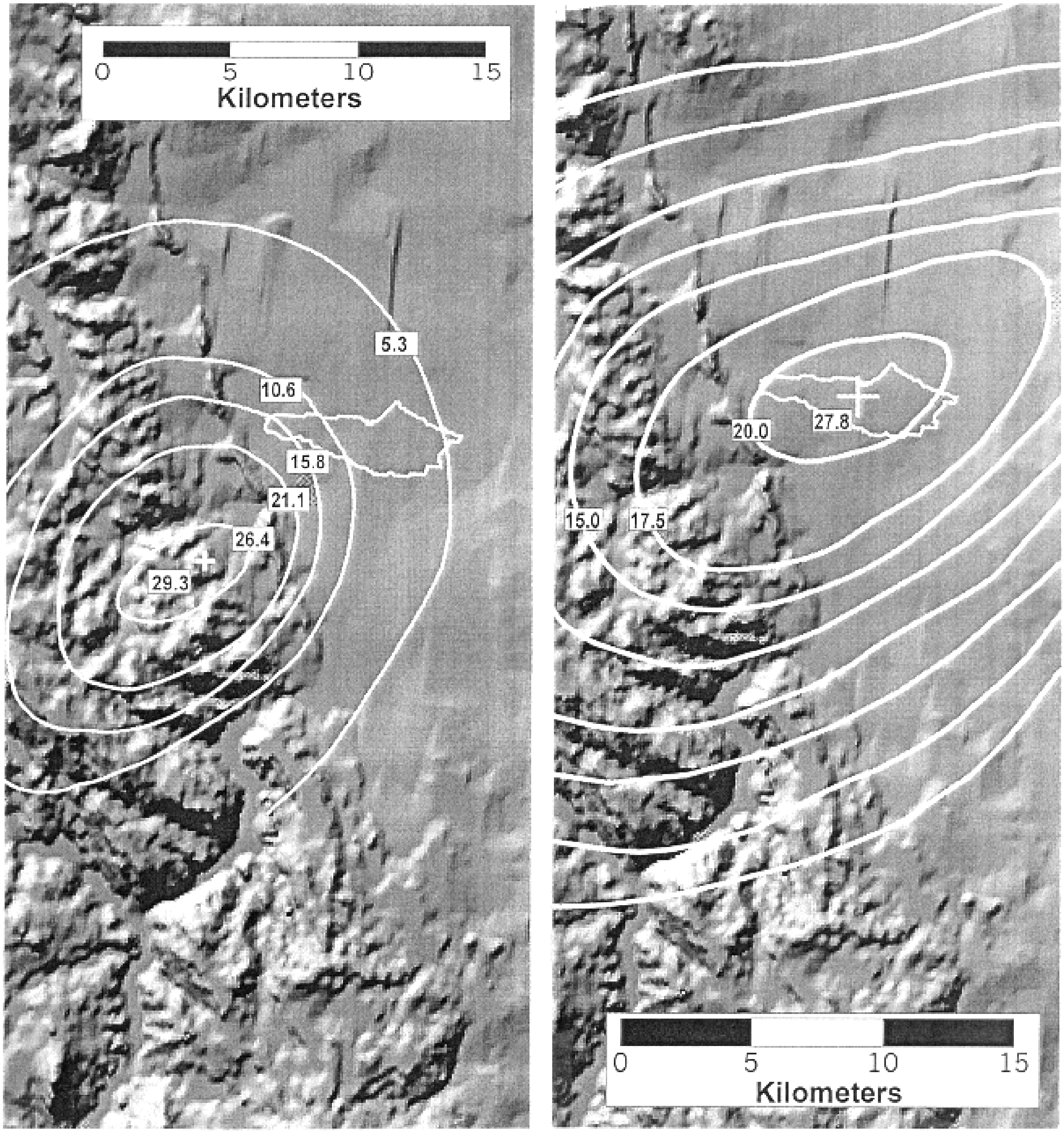


FIGURE 1: SOUTH PLATTE RESERVOIR GENERAL PLAN AND LOCATION



(a) (b)

Figure 2. Isohyets for the maximized (a) Kiowa, CO (1935) orographic storm center and (b) the Hale, CO (1935) non-orographic center as transpositioned and centered near or over the South Platte Reservoir Drainage. Shaded relief is used to depict the area terrain. The isohyet labels are in inches.

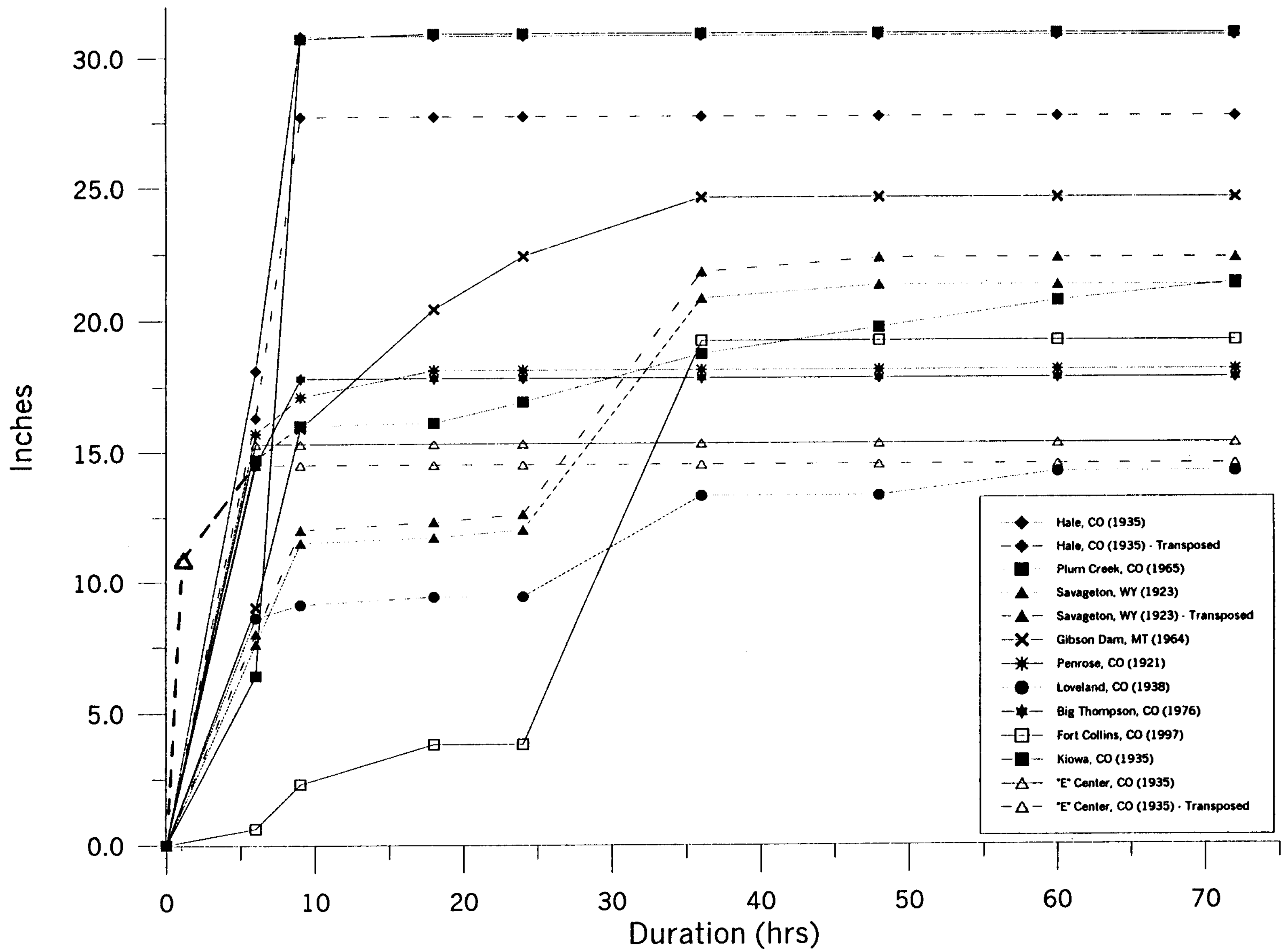


Figure 3. Historic storm rainfalls (inches) as maximized in-place (solid lines), and transposed to the South Platte Reservoir Drainage (dashed lines).