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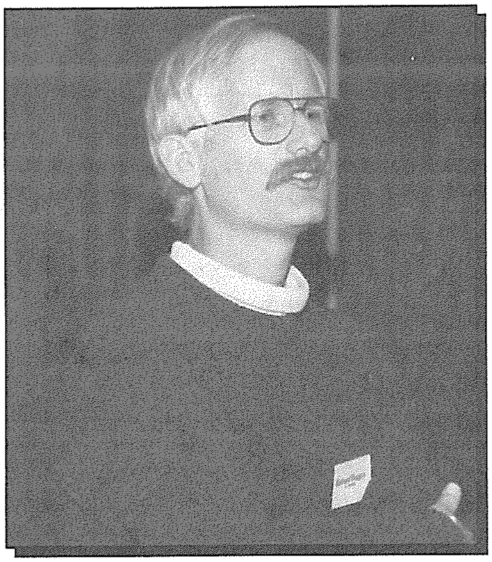

FLASH FLOODS: TWELVE OBSERVATIONS FOR URBAN WATER RESOURCE MANAGEMENT

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INTRODUCTION

Albuquerque is a regional leader in the establishment of hydrologic design criteria for municipal development. The City, the County and the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) have adopted common Development Process Manual (DPM) standards that satisfy the level of flood protection promulgated by the Federal Emergency Management Agency (FEMA).

Albuquerque has pursued basic hydrologic field research, literature review and computer code development in pursuit of appropriate design and consistent methods. The process is ongoing and under regular improvement.

This paper summarizes 12 general observations regarding flash floods in a metropolitan area. It also reviews the general experience in Albuquerque, discusses the data necessary for decision making, and summarizes challenges of comprehensive planning.

The observations fall into five categories. Observations 1 and 2 deal with precipitation. Observations 3 and 4 deal with abstractions. Observations 5 and 6 deal with hydrographs. Observations 7 and 8 deal with sediment. Observations 9 to 12 deal with water resource management.

Observation 1: Peak Precipitation Timing and Intensity

The Soil Conservation Service (SCS) has been the lead agency in establishing New Mexico hydrological practices, among them the standard storm distributions. The SCS distribution types 11 and 11a, applied extensively in New Mexico, describe a 24-hour storm with peak intensity at 12 and 6 hours, respectively. Hours of drizzle saturate the watershed before the storm peak hits. The peak runs off at a high discharge rate.

The 60-year record of major New Mexican storms indicates, on the average, that the peak rainfall intensity occurs approximately 40 minutes after storm initiation. The major portion of the total rainfall tends to occur within 2 to 3 hours.

In most New Mexican cases, peak rainfall falls on a land surface still capable of infiltration. The resultant abstraction diminishes the flood peak. Applying the same rainfall depth with an earlier peak than that assumed by the SCS can decrease the maximum discharge rate in the order of 10 percent.

The DPM places the storm peak at 84 minutes, a negotiated compromise between FEMA, who conservatively wants a late peak, and the City, where conventional practice tended to use a 30-minute positioning.

Timing data come from recording rain gages, of which New Mexico has few. The gage must be centrally situated within a major storm cell. Albuquerque's long-term gage at the Airport has almost never caught the major storms in the Northwest Heights or the West Mesa.

The peak timing record is sparse but reasonably established. In specifying the rainfall input for runoff models, the analyst must balance the data record, the agency norms, and the conservative preference of the project.

Southwestern data overwhelming indicate that intensities during the peak of a storm are greater than the estimates nationally prescribed by the National Oceanic and Atmospheric Administration (NOAA) Atlas. To comply with FEMA, Albuquerque acquiesces to the NOAA values. AMAFCA is contributing to a NOAA study to update (and likely increase) the peak intensity estimates.

Observation 2: Design Storm Return Period

The risk aspect of a flood control project is incorporated in the rainfall return period. Albuquerque designs for a 100-year event. Smaller communities may expose themselves to more risk, but save some capital expense, by designing for a 50-year storm. Where a rural road overtopping is occasionally acceptable, the New Mexico State Highway and Transportation Department sizes culverts for a 10-year event. Some federally sponsored projects involving potential exposure of hazardous waste use return periods exceeding 500 years.

Whatever return period is institutionally established, events resembling the design event may seem to occur more often than expected. In the past 15 years, Albuquerque has experienced at least two storms of 4 to 5 inches, arguably of return periods exceeding 500 years.

The reason relates to spatial independence. A storm near Tramway is likely to be meteorologically, and thus statistically, independent from a South Valley storm. As convective storm cells rarely exceed a few miles in diameter, five dispersed sites in Albuquerque may have five distinct precipitation histories. City wide, a 100-year event may thus occur on the average five times per century.

Observation 3: Watershed Infiltration

Whereas numerous abstraction mechanisms operate between rainfall and runoff, the lumped process can be called "infiltration" for most practical purposes. Infiltration can be modeled with a variety of algorithms, three of which merit discussion.

The Curve Number (CN) method models abstractions as an initial loss calculable from the CN and a subsequent decaying loss related to rainfall. In New Mexico, the CN approach regularly underestimates runoff early in the storm and overestimates runoff later. To replicate real behavior, the CN must itself decrease during the event. While an expertly determined CN may provide a reasonable estimate of total infiltration, its assumptions are blatantly invalid and its use in event modeling is likely to be erroneous.

The DPM models an initial abstraction and subsequent uniform loss based on field measurements. While the model is simplistic, the results, both overall and within the event, provide a reasonable fit to rainfall-runoff records. The Albuquerque model is incorporated in the computer code AHYMO, one of a handful of nonfederal models approved by FEMA for floodplain mapping. Where AHYMO is applied elsewhere in New Mexico, the default abstraction coefficients may need adjustment for non-Albuquerque soil types, cover complexes and land uses.

The Green-Ampt infiltration equation is physically based and, significantly in an arid zone, accounts for moisture-dependent matric suction. Arizona practice has successfully incorporated this approach. The potential for accordingly upgrading New Mexican practice is good.

Observation 4: Channel Losses

From the watershed perspective, channel losses are generally only a minor water balance component. Most infiltration occurs in the overland flow phase. Lining the channel, or leaving it with a natural bed, is unlikely to appreciably change overall watershed yield or recharge.

Channel losses can be significant to the hydrograph itself. Channel losses sometimes cause a volumetric decrease in the downstream direction. More commonly, channel losses manifest as a disproportionately small increase in discharge in relation to increasing tributary area.

Most infiltration into channel beds is eventually evaporated or evapotranspirated. Relatively little traverses the long vadose path to the water table.

In Albuquerque, channel losses are not relied upon for flood mitigation. Antecedent streamflow may have saturated the bed.

Observation 5: Periodic Waves

Surge or periodic waves are the slugs of water that roll down the channel during the rising or peaking hydrograph. Flood victim rescue efforts have been hindered by overpowering "walls of water."

Ephemeral runoff in steep channels often satisfies the rather narrow set of fluid mechanics constraints under which periodic waves occur. Periodic waves can double the high water marks in a channel, leading hydraulic reconstruction based on steady state formulae to overestimate the flood magnitude.

In a given event, periodic waves are few and short in duration. True high water impingement on a bridge chord might destroy the structure. True high water above a berm will flood the protected area. A few high waves, however, in either case may cause less extensive problems.

Propensity for periodic waves should be evaluated. If watershed or structural management cannot allow occasional splashes or sloshes, standard freeboard needs to be appropriately raised.

Observation 6: Flood Routing

The Muskingum-Cunge flood routing method is a modified diffusion equation variation of kinematic routing. The form of the solution resembles that of the hydrologic Muskingum method. The Muskingum-Cunge flood routing method has gained wide acceptance in the past several years.

Muskingum-Cunge parameters are measurable and physically based. The method requires no historical flood record. The method provides physical understanding of more-familiar Muskingum coefficients. The method performs well over a wide range of flows.

The solution is independent of the user-specified computation interval. The solution is a linear algebraic equation, rather than a finite difference or characteristic approximation. The solution allows more flexibility in time and distance increments than does the kinematic wave solution.

Albuquerque has incorporated Muskigum-Cunge into AHYMO. The method is particularly apt at matching steep arroyo behavior, common in Albuquerque, where the hydrograph peak does not attenuate.

Observation 7: Sediment Yield

Sediment yield estimates are inexorably tied to the multiplicative Universal Soil Loss Equation (USLE). There are few, if any, analytic alternatives. USLE estimates average annual soil displacement from small plots, not watersheds. If, in fact, a watershed behaves like an integral of plot-like components, USLE works. If, on the other hand, a watershed contains channels degrading or aggrading, playas, sediment traps, etc., USLE requires manipulation.

USLE is not well suited for environments where sediment transport is severely discontinuous.

In New Mexico, arroyo banks may slough for years without appreciable downstream transport. A large event then moves the mass as a slurry. As the flood peak may be quick, the load travels only a short distance before it redeposits.

The Modified USLE (MUSLE) transforms USLE into an event-specific model. Unfortunately, MUSLE remains prone to many of the USLE weaknesses, the most damaging probably being the exclusion of sediment entrained from the channel perimeter. AHYMO includes a MUSLE capacity. Experience (which is unfortunately weak in numerical content) indicates that the MUSLE result may be 3 to 10 times lower in watersheds where channels are degrading. At the other extreme, MUSLE may overestimate soil loss in watersheds after development.

Albuquerque now evaluates all flood control projects for both water and sediment yield. It is imperative that the sediment analyses be improved.

Observation 8: Sediment Routing

Like water, sediment flows downstream. Unlike water, however, sediment is also the substance of the unlined channel perimeter. Sediment routing is more than simply translating dirt downstream. Material scours. Material deposits.

Sediment routing in Albuquerque typically consists of both wash load and bed material load components. The wash load may be the MUSLE result. For unlined channels, the bed material load component is the remaining transport capacity. Modeled over the domain of channel reaches and discharge, this "routing" can identify zones of aggradation and degradation. The former is a potential problem of conveyance loss; the latter, a potential problem to structural foundations.

Improved routing algorithms such as HEC-6 adjust the channel geometry in accord with sediment translation. Unfortunately, the rapidity of hydraulic changes associated with ephemeral runoff invalidates the routine's assumption of steady-state time steps and the results are unreliable.

AHYMO includes a rudimentary sediment routing capacity. The coefficients are not necessarily calibrated for particular channels, however. The missing link is a straightforward, though wet and dangerous, job—synoptic stream gaging and suspended sediment sampling up and down a channel over flood events.

Comprehensive water resource planning in a desert environment needs to foresee changes in terrain, where headcuts may occur, where channels and basins may sediment.

Observation 9: Hydraulic Structures

Following are several observations related to hydraulic structures. The list illustrates the realm of concerns that make engineering not a cookbook endeavor.

- Supercritical baffle chutes can work. Rather than slope a channel naturally and experience high erosive velocities, flatten the grade and drop the bed with baffle chutes tested in New Mexico.
- Remove the bottom sills. Concrete lined channels may need artificial roughness. Bumper-barrier sills on the bed add some roughness, but hinder channel maintenance. Sills on the sidewall may be sufficient.
- Line up the confluences. When channels merge, close alignment mitigates standing waves. Minimize splitter walls to enhance the lateral spread at confluences. Single discharge in a confluence can be worse than dual discharge. Some structures which work well for full discharge experience wave problems with partial flow.
- Watch for inlet choke. If discharge cannot enter a watercourse, the watercourse serves no purpose. The hydraulic constraint on many conduits and channels is the entrance.
- Soil cement benches can work as spillways. Soil cement is more aesthetic than reinforced concrete and can conform to any alignment and cross section. Soil cement can handle large discharges. There are many compromises between a pristine arroyo and a linear concrete trapezoid. (A handy term is "naturalistic.")
- Safety grates can work in supercritical flow. A channel can be engineered to deliver a victim to safety.
- Unlined channels require perpetual management. There's no free lunch. The unfettered arroyo changes direction, scouring here and filling there. From a geomorphic perspective,

the process is the nature of things. From the urban management sense, the process can be disastrous.

Observation 10: Conjunctive Use

The State Engineer limits floodwater detention to 96 hours to minimize evaporation and infiltration of water that may belong to a downstream user. From a legal perspective, this may be a nonnegotiable constraint. From a flood protection perspective, it is best to drain the reservoirs rapidly. From a water management perspective, however, the consequence can be unfortunate. Were water stored longer, it might be available for recharge, recreation, irrigation, or habitat.

Without fundamental change in regulation, floodwaters are effectively lost as a conjunctive use option.

Observation 11: Water Quality

Albuquerque is now engaged in the NPDES discharge permit process and is evaluating water quality aspects of stormwater discharge. As the extent of the law is not yet well established and the quality of the runoff is not yet well documented, where this process will end is not known.

As with many standards, their formulation is likely derived from experiences in areas of perennial runoff. The high volume and rapid rate of runoff in the Southwest make difficult some technologies or management practices suited for elsewhere.

Albuquerque has had few, if any, publicly recognized problems of "polluted" arroyo flows. The most notable objectionable constituent may be shopping carts, currently not falling under EPA's regulation. Suspended sediment levels can be in the percentage level, not ppm level, but that is what would be expected in a natural setting. The City has included an oil-separating hood on the outlet of a dentition basin, but only time will tell if the inflow contains measurable oils.

In some cases, protection may exceed the problem.

Observation 12: Land Use

Flood management's clout in conjunctive management appears to be in multiple use of real estate. Albuquerque flood control structures incorporate trails, golf courses, parks, playing fields, bikeways and open space. Channels and embankments are increasingly designed to blend into the environment.

Development setbacks are no longer simply the 100-year flood elevation, but must also protect against potential channel meanders, avulsions and grade adjustments. Albuquerque is the leader in "Prudent Line" easements. The net consequence is more than increased flood safety. The undevelopable land becomes a perpetual resource for other nondisruptive land uses.

Flood control planning can be an enabling tool in comprehensive land use planning. Flood conveyance carries strong legal authority to preemptively, or even retroactively, restrict land use over large, contiguous areas. Coordinated flood protection and creative public land use can march hand-in-hand.