LOWER DES PLAINES RIVER
DETAILED WATERSHED STUDY

CALIBRATION AND VERIFICATION
USING
CLARK’S UNIT HYDROGRAPH METHODOLOGY

Presented by:

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PRESENTATION OVERVIEW

- District Detailed Watershed Plan
  - Development and purpose
  - Watershed Planning Council participation
  - Implementation
- Lower Des Plaines River Watershed
  - Detailed Watershed Plan tasks and goals
  - Discussion of Unit hydrograph options and selection
  - Calibration examples
- Summary
DETAILED WATERSHED PLAN DEVELOPMENT

• Cook County Stormwater Management Plan (CCSMP) adopted by Board of Commissioners in February 2007

• Chapter 6 of the CCSMP provides guidance for Detailed Watershed Plan (DPW) development

• DWPs developed for Poplar Creek, Upper Salt Creek, North Branch Chicago River, Lower Des Plaines River, Calumet Sag, and Little Calumet River Watersheds

• District enlisted Christopher B. Burke Engineering, Ltd. to assist in preparing Lower Des Plaines River DWP

• District led information-gathering effort by requested existing stormwater related background data, studies, and problem area locations from stakeholders
DETAILED WATERSHED PLAN PURPOSE

• Identify the stormwater related problems in the watersheds
  • Flooding
  • Erosion
  • Water quality

• Classify identified problems as Regional, Modeled, or Local
  • Regional:
    • Multi-jurisdictional waterways with at least ½ mi² drainage area
    • Roadways and bridges impacted by overbank flooding of regional waterways at depths exceeding 0.5 feet
    • Erosion along regional waterway posing imminent risk to structures or critical infrastructure
  • Modeled:
    • Structures, roadways, and bridges within inundation area meeting regional problem criteria
  • Local:
    • Not related to overbank flooding of regional waterway
DETAILED WATERSHED PLAN PURPOSE

- Develop alternative solutions to Regional and Modeled problems
- Evaluate alternative solutions to determine most effective
- Provide report summarizing:
  - stormwater problem areas
  - comprehensive evaluation
  - Listing proposed regional capital improvement projects
DETAILED WATERSHED PLAN PHASES

• Phase A
  • Gather existing background information on current watershed conditions and past studies
  • Analyze the suitability of existing information
• Phase B
  • Develop hydrologic and unsteady hydraulic models of the watershed
  • Identify potential projects to address stormwater problems
  • Evaluate alternative projects
  • Quantify benefits through economic analysis of property damage from flooding, streambank erosion damage, and transportation damages
WATERSHED PLANNING COUNCIL PARTICIPATION

Watershed Planning Council Workshops

- Workshop #1:
  - Classification of reported problems
  - Draft inundation maps
  - Open space discussion

- Workshop #2:
  - Preliminary alternatives

- Workshop #3:
  - Final alternatives
DETAILED WATERSHED PLANS TO CAPITAL IMPROVEMENT PROJECTS

• Draft watershed plan report reviewed by Watershed Planning Council
• Recommended capital improvement projects reviewed on countywide basis
• Priority for project implementation determined by District’s Board of Commissioners
• District will enlist assistance of consultants to develop detailed design documents for project implementation
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  • Discussion of unit hydrograph options and selection
  • Calibration examples
  • Summary
- 15 Tributaries +
  - Mainstem Des Plaines River

- USGS Stream Gages:
  - Tributaries: 6
  - Des Plaines River: 4

- Watershed areas:
  - Varied from 0.26 mi$^2$ to 27.0 mi$^2$
  - Salt Creek Watershed = 150 mi$^2$
  - Des Plaines River = 680 mi$^2$
PHASE B BREAKDOWN

• Prepare hydrologic (HEC-HMS) and hydraulic (Unsteady HEC-RAS) models
• Calibrate/verify models using available USGS gage records and surveyed HWM’s
• Develop 2-, 5-, 10-, 25-, 50-, 100-, and 500-year flood profiles
• Prepare 100-year storm event flood inundation maps
• Calculate economic damages for structure/property, streambank erosion, and transportation
• Develop alternatives to address Regional and Modeled Problem Areas
• Alternative analysis:
  • determine flood damage reduction benefits
  • develop conceptual cost estimate
  • determine Benefit-Cost ratio
THE LOWER DES PLAINES RIVER WATERSHED STUDY

• H&H Modeling Goals:
  • Evaluate runoff hydrograph options
  • Develop H&H models
  • Calibrate/verify gaged watersheds models to September 13-14, 2008 storm event
  • Apply adjustment factor to ungaged watersheds
SCS Dimensionless Unit Hydrograph

- Derived from a large number of natural unit hydrographs from agricultural watersheds varying widely in size and geographic location

- \[ q_p = K \frac{A Q}{T_p} = \frac{484AQ}{0.5 \Delta D + 0.6 T_c} \]

Where:
- \( q_p \): Peak Discharge (cfs)
- \( A \): Area (mi\(^2\))
- \( Q \): Runoff (inches)
- \( T_p \): Time to Peak (hours)
- \( \Delta D \): Duration of unit excess rainfall
- \( K \): Peak Factor Rate (controls shape of unit hydrograph)

(K = 484: standard default for TR-20, HEC-1, and HEC-HMS hydrologic models)

- Required parameter: Time of Concentration (\( T_c \))
Sensitivity of SCS Triangular Unit Hydrograph to K

Given: $A = 1.0 \text{ mi}^2$
$Q = 1.0 \text{ inch}$
$T_c = 1.0 \text{ hour}$

- $K = 600$
  - Little storage
  - Steep terrain

- $K = 484$
  - Default

- $K = 300$
  - Significant ponding
  - Flat terrain
UNIT HYDROGRAPH OPTIONS

SCS DIMENSIONLESS UNIT HYDROGRAPH

Example:

• SCS Des Plaines River Floodwater Management Plan – 1976

• SCS developed a TR-20 hydrologic model of Willow Creek Watershed
  • Calibrated to USGS Gage (Willow Creek at Orchard Place, discontinued 1979)

• Calibration achieved using K = 218

• Entered into TR-20 using dimensionless unit hydrograph

• If HEC-1, modification of subroutine in source code calculating dimensionless unit hydrograph. Recompile to make new executable HEC-1 file.
Explicitly represents two critical processes in transformation of excess precipitation to runoff:

**Translation:**
- Movement of the excess from origin, throughout the drainage area, to watershed outlet
- represented by time-area relationship

**Attenuation:**
- Reduction of magnitude of discharge as the excess is stored throughout watershed
- represented by linear storage reservoir (allows for accounting of natural storage areas located within watershed)

• Required parameters are Time of Concentration ($T_c$) and the Storage Coefficient ($R$)
INITIAL R COEFFICIENT DETERMINATION

• Method to estimate Clark’s Unit Hydrograph parameters ($T_c$ and $R$)
• Regression equations based on results from 98 gaged watersheds in Illinois
• HEC-1 hydrologic models developed and calibrated for each gaged watershed
• Watersheds included both rural and urban conditions
• Study concluded method could be used for rural and urban watersheds
• $(TC + R) = 35.2 \ L^{0.39} \ S^{-0.78}$ where:
  • $L$ = Stream Length
  • $S$ = Slope
• $R/(TC+R) = \text{Regional values (LDPR watershed used 0.7)}$
INITIAL R COEFFICIENT DETERMINATION

Figure 1.—Regional values of \( R/(TC + R) \).

Source: ISWS
CLARK'S UNIT HYDROGRAPH METHOD
APPLICATION TO LDPR WATERSHED

• USGS Regression Equations used to establish $T_c$ and $R$

• $R$ chosen as calibration parameter

• $R$ multiplier uniformly applied to all subbasins in a sub-watershed (HMS)

• Calibration checked at USGS gage location in Unsteady HEC-RAS

• For the 6 gaged tributaries, $R$ multiplier varied from 1.65 to 3.00

• Relationship between the $R$ multiplier and stream slope was developed for gaged tributaries

• Relationship then used to establish $R$ multiplier for ungaged watersheds
EXAMPLE CALIBRATION:
SEPTEMBER 13-14, 2008 STORM EVENT

FLOW (cfs)

USGS GAGE: WELLER CREEK AT DES PLAINES

DRAINAGE AREA = 19 MI²
GAGE AT 70% WATERSHED AREA

1,310 cfs OBSERVED
EXAMPLE CALIBRATION:
SEPTEMBER 13-14, 2008 STORM EVENT

USGS GAGE: WELLER CREEK AT DES PLAINES

FLOW (cfs)

2,665 cfs SCS
1,310 cfs OBSERVED


TIME
Example Calibration:
September 13-14, 2008 Storm Event

USGS Gage: Weller Creek at Des Plaines

FLOW (cfs)

2,665 cfs  SCS
2,140 cfs  CLARK’S R x 1
1,310 cfs  OBSERVED

Example Calibration: September 13-14, 2008 Storm Event

USGS Gage: Weller Creek at Des Plaines

Flow within 68% of Observed, SCS
Flow within 24% of Observed, R x 1
Flow within 11% of Observed, R x 2.4
UNIT HYDROGRAPH SELECTION

SCS vs. Clark’s

• SCS Dimensionless Unit Hydrograph
  • $K = 484$ does not represent properties of all LDPR watersheds
  • Difficult to modify $K$ value in hydrologic modeling to account for natural storage routing
  • Resultant combined hydrograph peak discharges can be over estimated due to “peak on peak” addition
  • Adjustment of $K$ should be based on natural surface storage rather than watershed slope (T. Suphunvorranop, 1985)

• Clark’s Unit Hydrograph
  • Previously applied to several LDPR tributaries
  • Accounts for natural storage routing
  • Accepted process for calculating Runoff Curve Number (CN) and $T_c$
  • $R$ coefficient could be used as a calibration parameter for gaged watersheds
  • Relationship for $R$ vs. stream slope could be applied to ungaged watersheds
Observed Stage = 665.38 ft
Stage R x 1 = 665.47 ft
Volume within 17% of Observed, R x 1

USGS GAGE: BUFFALO CREEK NEAR WHEELING

DA = 27 MI²
75% WATERSHED AREA
Observed

Stage $R \times 2.5 = 665.38$ ft
Stage $\times 2.5 = 665.41$ ft
Stage $R \times 1 = 665.47$ ft

Volume within 2% of Observed, $R \times 2.5$
Volume within 17% of Observed, $R \times 1$
OBSERVATIONS

• Clark’s Unit Hydrograph calibration
  • R resulting from standard calculation was insufficient
  • R multiplier improved hydrograph shape compared to observed data
  • No need for additional calibration using parameters with accepted calculation methodologies such as of CN or $T_c$
  • R multiplier calibration can vary based on:
    • Stream slope
    • Watershed shape
    • Number of modeled storage areas (including ponds, flood control reservoirs, natural storage)
  • Tributaries with higher percent of storage areas modeled required lower R multiplier
22 mi², 8 Flood Control Reservoirs
Approximately 1,800 A-F
R x 1.65
22 mi², 60% of Watershed in DuPage County
Limited Modeling of Storage Areas
R x 3.00
CLARK’S UH CALIBRATION ADVANTAGES

- LDPRDWP Advantages:
  - Continued use of Clark’s Unit Hydrograph per previous studies
  - Methodology applicable throughout entire study area
  - No need for additional calibration using parameters with uniform calculation methodologies such as Runoff Curve Number or $T_c$
  - Considers storage factors not explicitly evaluated in H & H modeling efforts
  - Use caution when applying strictly to ungaged watersheds and model storage in detail.
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