HYDROLOGIC AND HYDRAULIC MODELING
OF THE MCCOOK AND THORNTON
TUNNEL AND RESERVOIR PLANS

Chicago, Illinois

DAVID KIEL, U.S. ARMY CORPS OF ENGINEERS
TUNNEL AND RESERVOIR PLAN

- Reduce waterway pollution from CSOs
- Prevent backflows to Lake Michigan
- Provide storage for floodwaters
  - Reduces basement flooding from CSOs
    (economic justification of project)
McCork Reservoir

250 feet deep
7 billion gallons

Des Plaines River

Lagoons

Sanitary & Ship Canal

I-55
PROPOSED LOCATION OF CUP 1/0 STRUCTURE

PROPOSED AVERAGE FLOOR EL. = -297.5 CCD
HIGH WATER LEVEL = -5.0 CCD
FREEBOARD = 5.0 TO 0.0 CCD

PROPOSED LOCATION OF THORN CREEK INLET STRUCTURE. DESIGN PENDING
PLUNGE POOL

PROPOSED CONCRETE PLUG

MSC HAUL TUNNEL TO BE PLUGGED BY RCC GRAVITY BAMA. DESIGN PENDING

PROPOSED RESERVOIR BOUNDARY

PROPOSED RESERVOIR BOUNDARY

LOW BENCH EL. = -209.5 CCD

UPPER BENCH EL. = -199.5 CCD

DIVERSION TUNNEL 22' INS.

TOLLWAY

EXIST CONSTRUCTION SHAFT

RELOCATED VICTERS RD

PROPOSED CONCRETE PLUG

TRANSITIONAL RESERVOIR DRAIN TUNNEL (BY WMROG)

N 1,791,180.25 E 696,452.47

N 1,791,822.19 E 696,407.54

N 1,791,557.39 E 696,452.71

N 1,791,120.25 E 696,452.47

BRIDGE

GENERAL RESERVOIR LAYOUT

FILED WALL
- Hydrologic Simulation Program - Fortran (HSPF)
- Hydraulic Sewer Routing Model, (SCALP)
- Special Contributing Area Loading Program
- Tunnel Network Model (TNET) for TARP, Tunnel and Reservoir Plan
- UNET Canal Model
- PAR3D Fluid Dynamics and Water Quality Model
- First 4 Models use DSS database
Summary of Models

HSPF

Meteorological and Precipitation Data

SCALP

Unit Runoff Information

Flows in Sewers and Overflows

TNET

UNET

Flows in Sewers and Overflows

PAR3D

Overflows to River

Reservoir Fill Frequency and WQ Data

River Stages

Aeration and Washdown Systems

Overflows to River
HSPF: HYDROLOGIC SIMULATION PROGRAM - FORTRAN

- Continuous simulation of rainfall-runoff process including snow accumulation and melt
- Physically based model representing:
  - interception storage above soil
  - infiltration through soil
  - storage within soil (upper and lower zones)
  - losses to deep aquifer
- 39 parameters define soil, land cover, infiltration rates, etc.
HSPF RUNOFF COMPONENTS

- Surface Runoff
- Interflow
  - infiltration that moves laterally through soil towards stream
  - function of infiltration rate and soil moisture
- Active Groundwater or baseflow
Figure 4.2(1).3-1 Hydrologic cycle
HSPF WATER STORAGE

- Defines antecedent soil moisture at start of an event
  - interception storage
  - surface storage
  - interflow storage
  - upper zone storage
  - lower zone storage
  - active groundwater storage
HSPF MODEL

- 13 Precipitation Gages thru WY89, 25 Gages WY90
- Theissen Polygons define 13 and 25 areas
- 3 Land Type Runs
  - Impervious
  - Grassland
  - Forestland

<table>
<thead>
<tr>
<th>Land Type</th>
<th>Unit Area Runoff Output (in/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPRO</td>
<td></td>
</tr>
<tr>
<td>OLFRO</td>
<td></td>
</tr>
<tr>
<td>SUBRO</td>
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</table>

- IMPRO = impervious runoff
- OLFRO = pervious surface runoff
- SUBRO = pervious subsurface runoff
  = interflow + active groundwater
HSPF MODEL INPUT

- Meteorologic Input
  - Precipitation (13 and 25 gages)
  - Air Temperature (4 gages)
  - Dew Point
  - Wind
  - Cloud Cover
  - Solar Radiation
  - Evapotranspiration
HYDRAULIC SEWER ROUTING MODEL - (SCALP)

- Input is HSPF runoff output (IMPRO, OLFRO, SUBRO) from Impervious and Grassland runs
- 3 MWRDGC WRP service basins modeled
  - Stickney
  - Northside
  - Calumet
SCALP MODEL SUBBASINS

- Each MWRDGC service basin subdivided into combined and separate sewer subareas called SCAs (Special Contributing Areas)

<table>
<thead>
<tr>
<th></th>
<th>Combined</th>
<th>Separate</th>
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<tr>
<td>Stickney</td>
<td>100</td>
<td>3</td>
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<tr>
<td>Northside</td>
<td>33</td>
<td>2</td>
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<tr>
<td>Calumet</td>
<td>64</td>
<td>8</td>
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SCALP MODEL

- Sewer flows based on linear storage routing scheme
  - Lateral sewers
  - Submain sewers
  - Main sewers
- 3 Sources of Sewer Flow
  - Wastewater (Sanitary)
  - Stormwater Surface Runoff (Inflow)
  - Stormwater Subsurface Runoff (Infiltration)
SCALP AREA DETERMINATION

- Impervious and Grassland Area based on 161 1”=400’ Aerial Photos from 1990
- Photos subdivided into 10 landuse categories each with assumed %’s for impervious, grassland, and forestland
SCALP OVERFLOW SIMULATION

- Based on Q SPLIT
  - Flows in excess of Q SPLIT are overflows
- 8 Flow Outputs for each SCA
  - WRP: Inflow, Infiltration, Sanitary, Total
  - OVF: Inflow, Infiltration, Sanitary, Total
- 8 Water Quality outputs for each SCA
  - WRP: BOD, DO, TSS, Water Temperature
  - OVF: BOD, DO, TSS, Water Temperature
- Modeled interceptor flows calibrated at WRPs
- Total OVF's are routed to TARP (Tunnel and Reservoir) Tunnels as input to TNET model
TARP TUNNEL NETWORK MODEL - (TNET)

- Modified version of UNET, the one dimensional unsteady state flow model for open channel flow developed by Dr. Bob Barkau
- TNET solves the unsteady flow equations of continuity and momentum and adds a Priesmann slot for pressurized flow forcing the open channel flow equations to correctly propagate the high celerity of the pressure waves
- Total OVFss including flow and water quality data (SCALP output) from individual SCAs are routed to TARP tunnels through drop shafts
- Model simulates operation of drop shaft gates, main inlet gate, the pumping station, WRP operations, and overflows into the canal system
Mainstream/Des Plaines TARP (McCook)
- 175 dropshafts, 136 subareas

Calumet TARP (Thornton)
- 84 dropshafts, 69 subareas
• Flow into the tunnels is controlled by dropshaft gates which are opened or closed based on MWRDGC Operation Plan

• TNET models gate openings and closings based on Index Drop Shaft(s)

• Operation of TARP pumps controlled by:
  - tunnel water surface elevation at pump
  - available treatment plant capacity (based on simulated interceptor flows from SCALP)
TNET TARP MODEL - MCCOOK

- Dry weather WRP capacity 1900 cfs
- Maximum WRP capacity 2200 cfs sustained during event and until tunnels are pumped dry
- TNET outputs hourly data and stores them in a unique DSS pathname
  - overflows to river from each dropshaft or dropshaft grouping
  - gravity inflows to reservoir
  - pumping from tunnels to reservoir
  - pumping from tunnels to WRP
  - pumping from reservoir to WRP
  - water quality data in the reservoir
    - BOD, DO, TSS, Water Temperature
TNET – MODELED EVENTS

• 52 Year Period of Record (1949 – 2000)
• Synthetic Events
  - 1, 2, 5, 10, 20, 50, 100 and 500-Year storms
  - SPF's and PMP's for 1954 and 1957
MCCOOK RESERVOIR WITH STAGE 2 (STP CAPACITY = 1900 cfs NORMAL, 2200 cfs MAX.)

STAGE 1 RESERVOIR MAXIMUM DAILY STAGE
STAGE 2 RESERVOIR BEGINS FILLING WHEN STAGES EXCEED WEIR & -200 CCD
GRAVITY FLOW AND PUMPING TO RESERVOIR FOR SMALL EVENTS
<table>
<thead>
<tr>
<th>Target Elevation Exceeded (ft. CCD)</th>
<th>Number of Specific Events</th>
<th>Maximum Event Duration (days)</th>
<th>Average Event Duration (days)</th>
<th>Total Days Exceeded (days)</th>
<th>Percent of Time Exceeded (%)</th>
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<tbody>
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<td>13</td>
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**Stage II Reservoir**

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<tr>
<th>Number of Specific Events</th>
<th>Maximum Event Duration (days)</th>
<th>Average Event Duration (days)</th>
<th>Total Days Exceeded (days)</th>
<th>Percent of Time Exceeded (%)</th>
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**Note:** The period of record spans 40 years, from 01JAN1949 to 31DEC1988. The stage-storage curve used for this analysis was developed in July 1998. Any later revisions are not reflected. The Stage I reservoir target elevation extends to only -283 and the Stage II reservoir target elevation extends to only -275 because the model leaves some water near the reservoir floor for computational stability. The Stage I and Stage II reservoirs will respond the same above elevation -200 CCD.
UNET CANAL MODEL

- Simulates the operation of the canal system including operations at Lockport (including drawdowns) as well as backflows to Lake Michigan
- Input is TNET TARP model overflow output
- Input also includes stream gage records (recorded for POR, simulated for synthetic events), and simulated ungaged area inflows
- Calibrated at Lockport
PAR3D MODEL

- PAR3D – computational fluid dynamics model used to model fluid dynamic and water quality related processes for the water in the reservoir.
- Developed by Dr. Bob Bernard of the Coastal and Hydraulics Laboratory at WES, the Corps of Engineers Waterways Experiment Station
- Processes modeled include: gas transfer from the water surface and from bubbles, biochemical oxygen demand, sediment oxygen demand, and sedimentation.
Summary of Models

Meteorological and Precipitation Data

HSPF → Unit Runoff Information → SCALP → Flows in Sewers and Overflows → TNET

River Stages

UNET

Aeration and Washdown Systems

PAR3D

Reservoir Fill Frequency and WQ Data

Overflows to River

Flows in Sewers and Overflows

Stages
WES PHYSICAL MODELS

- Main Tunnel inlet gates, inlet tunnels, sump, weir structure, stage 1 reservoir floor (1:40)
- Distribution Chamber (1:12)
  - gravity inflow gates and conduits for Des Plaines tunnel
  - gravity inflow
WES PHYSICAL MODELS

- Main Tunnel inlet gates, inlet manifold, sump, weir structure, stage 1 reservoir floor
  - 1:40 model to determine:
    - Velocities on the sump and stage 1 reservoir floor for aeration design and rock protection plan
    - Stepped weir loadings and adequacy of design for energy dissipation
    - Pressures in the gate chamber, inflow conduits, and inlet manifold
    - Adequacy of inlet conduit and manifold wrt flow conditions, air entrainment, air/water surging through vents
WES PHYSICAL MODELS

- Distribution Chamber (gravity inflow gates and conduits for Des Plaines tunnel gravity inflow)
  - 1:12 model to determine:
    - Operational constraints on the bonneted slide gates wrt headwater and tailwater conditions and gate closure speeds
    - Gate loadings and pressures within the conduits
    - Cavitation potential
    - Information on the transient hydraulics in the vicinity of the bifurcations
    - Recommendations for geometric and or material changes
ADDITIONAL MODELS

• MXTRANS Hydraulic Transient Model
  - University of Minnesota, St. Anthony Falls Hydraulic Laboratory
  - Applies to steady and unsteady flows including pressurized flows, free-surface flows and mixed flows
  - Based on explicit characteristic method
  - Interface between pressurized flow and free-surface flow (shock surface) is computed with the shock fitting method
  - Primarily used to determine
    - operational procedures for minimizing geysering through dropshafts
    - hydraulic loading on main gate
    - effect of main gate operation on hydraulic transients
WHAMO (water hammer and mass oscillation)
Hydraulic Transient Model
- Corps of Engineers (HDC) and Camp Dresser and McKee
- Applies to steady and unsteady fully pressurized closed conduit flows of various complexities and boundary conditions
- Based on implicit finite difference method
- Used to determine loadings on the distribution tunnels small gates and valves as well as surge effects resulting from various operations and misoperations of the system (including power failures)
- Operations investigated include pumping from tunnels to reservoir, pumping from tunnels to WRP, pumping from reservoir to WRP, and gravity inflows from Des Plaines tunnel
QUESTIONS?